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BOOK

(UNCL) AERIAL GUNNERY (STREL'BA v VOZDUKHE)

AUTHOR: G.P.NICHIK

SOURCE: STATE PUBLISHING HOUSE FCR THE DEFENSE INDUSTRY

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AERIAL GUNNERY

by

G. D. Nichik

Chapter II

FROM ARROWS AND "FLYING BULLETS" TO THE AUTOMATIC AERIAL GUN

1. The Earliest Devices Used from Airplanes against Ground and Air Targets

At the very beginning of the combat use of aviation, use was made of special heavy steel feathered arrows and bullets, which were dropped on heavy troop and cavalry concentrations, as well as on the enemy's lighter-than-air craft and airplanes.

The use of such devices in fighting the aerostats and airplanes of the enemy was responsible for shaping aerial tactics. The advantage of altitude was always required, and the arrows and bullets were released from above while passing over the target.

In the Russian air force, extensive use was made of V. A. Slesarev's "flying bullets"; V. A. Slesarev was the designer and builder of the heavy airplane "Svyatogor". He designed special cells which allowed the alternate release of bullets and arrows. Also widely used at the time were the bullet-releasing devices of the engineer Kolpakov-Miroshnichenko.

This type of aerial weapon was effective to a degree when used against ground personnel and aerostats, but was quite ineffective in action against enemy planes.

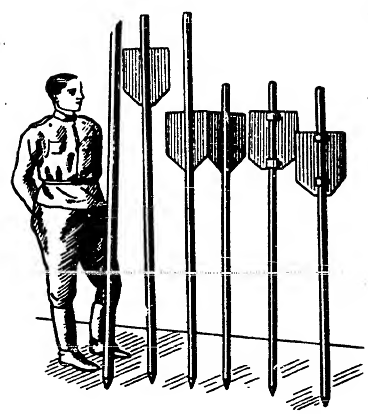

Fig. 1. Aircraft arrows. Arrows of this type were dropped by airmen on enemy troops, blimps and airplanes before firearms and bombs came into use in the air force.

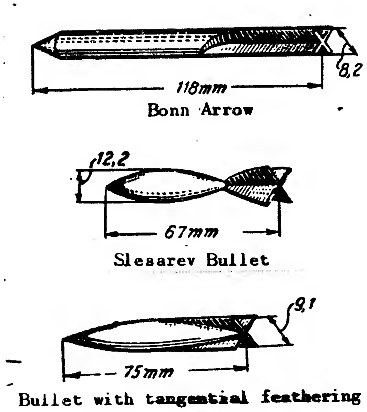

Fig. 2. "Flying" bullets and arrows, used by airplanes against enemy personnel and aircraft.

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Chapter VI

EFFECT OF ACTUAL SPEED ON PROJECTILE TRAJECTORY

47. Relative and Absolute Initial Velocities of Projectile. The Triangle of Velocities

It has happened to everyone to throw some relatively heavy object from the window of a fast-moving train or automobile.

You cannot help noticing that the object keeps falling alongside of you until it reaches the ground. This means that the train or car have imparted to it their own velocity, and that, after you have released it, the object continues to to travel at this velocity in the direction of your own motion, while falling downward because of the pull of gravity. The relative velocity of the object, i.e. its velocity in relation to the railroad car, will be directed vertically downward, while its velocity relative to the ground, i.e. its absolute velocity, may be obtained as the sum of the vector of train speed and of the vector of the speed of fall, increasing due to the pull of gravity. If we do not take air resistance into account, the motion of the released object will follow a parabola.

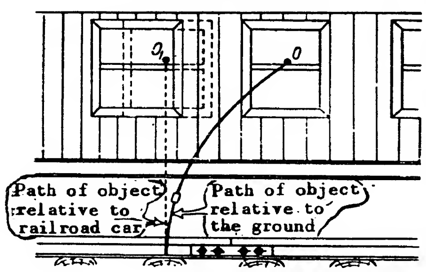

Fig. 75. Fall of object thrown from the window of a fast-moving train.

We get the same picture if we fire a gun installed on an airplane. At the moment of its exit from the bore of the gun, velocities are imparted to the shell in two directions: that of the bore axis, and that of the motion of the airplane. In relation to the gun and to the plane, the velocity of the projectile at the

moment of its exit will equal the velocity at which the gunpowder gases propel it out of the bore of the gun, or that initial velocity which would be imparted to the projectile if the same gun were fired on the ground. In aerial gunnery this velocity is termed relative initial velocity and designated as v_o.

Relative to the air, the velocity of the projectile will be different. To the vector of relative initial velocity will be added the vector of the airplane's speed and the direction and magnitude of projectile velocity will be represented by the diagonal of a parallelogram constructed from these vectors. The resulting velocity, obtained by summing relative initial velocity and the actual speed of the airplane is termed absolute initial velocity and represented by v_{o1}.

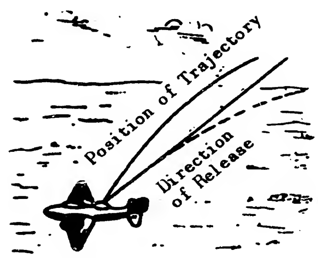

Fig. 76. This is the path of a projectile fired from an installation aboard a plane.

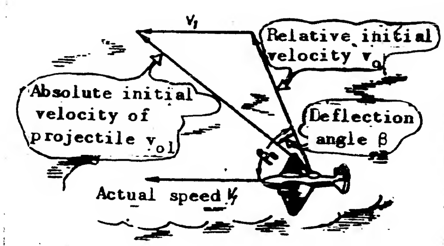

Fig. 77. Effect of actual speed on the position of the trajectory of the projectile. Construction of triangle of velocities.

The angle formed by the plane's fore and aft axis and the bore axis at the moment of firing may be described as the angle of inclination of release relative to the plane. It is represented as β_o. This angle is measured from the aft end of the plane's axis and may vary from 0 degrees, when firing is in the direction of flight, to 180 degrees, when firing aft. For bevity's sake, we will call this angle simply the angle-off of the piece.

The angle formed by the vector of absolute initial velocity and the fore and aft axis of the plane is termed the absolute angle-off, and is represented as β_{01}.

The angle formed by the vectors of the relative and absolute initial velocities is called the angle of deflection and represented as β.

The magnitude and direction of the absolute initial velocity of the projectile v_{01} depends (for a given piece) on the actual speed of the airplane and on the angle-off of the piece. The highest value for absolute initial velocity obtains when firing directly forward. It then equals the algebraic sum of relative initial velocity and the actual speed of the plane, while the angle of deflection equals 0. As the angle-off of the piece is increased from 0 to 90 degrees, the vector of absolute initial velocity decreases, while the angle of deflection increases. As the angle-off of the piece is further increased to 180 degrees, the vector of absolute initial velocity continues to decrease, while the angle-off decreases to zero. When firing directly aft, absolute initial velocity equals the algebraic difference between relative initial velocity and actual speed.

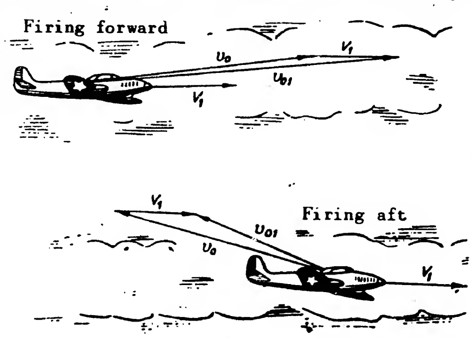

Fig. 78. In firing forward, the absolute velocity of the projectile is increased. In firing aft, it is decreased.

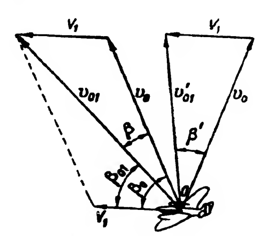

Fig. 79. The triangle of velocities is situated in the same plane as the fore and aft axis of the airplane.

The triangle formed by the vector of initial velocity v_o, the vector of the actual speed of the plane V_1, and the vector of absolute initial velocity v_{o1} is called the triangle of velocities. The fore and aft axis of the plane always lies in the same plane as this triangle.

Thus, if the angle-off of the piece differs from 0 or 180 degrees, the shell will never travel on the path onto which it has been released from the piece, while its velocity will differ from relative initial velocity.

The motion of the projectile when firing from aircraft in flight must be considered as taking place under initial conditions different from those obtaining in firing on the ground.

48. Deflection of Projectile. Linear and Angular Deflection

The phenomenon of the deviation of the projectile from the relative plane of release as a result of the actual speed of the airplane is called the deflection of the projectile. The magnitude of deflection may be estimated either as the linear or as the angular value of this deviation.

The distance measured along the line of flight from the relative path of release to the absolute path of release is termed linear deflection and is represented by the letter A.

Linear deflection varies in direct proportion to the range of firing and does not depend on the angle-off of the piece. The angle of deflection, whose definition we gave in the preceding paragraph, does not depend on the range of fire, but does depend on the angle-off of the piece.

A correction for deflection, therefore, may be introduced either by setting backward the point of aim from the target in a direction opposite to that of the motion of the gunner's plane to a distance equal to the magnitude of the deflection, or by turning the piece in the same direction at an angle equal to the angle of deflection.

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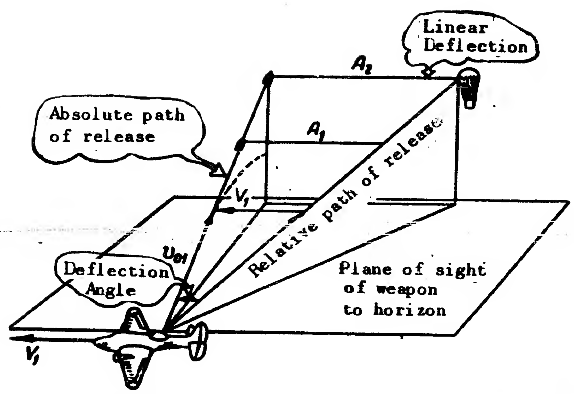

Fig. 80. Linear deflection of projectile is proportional to range. Deflection angle does not depend on range.

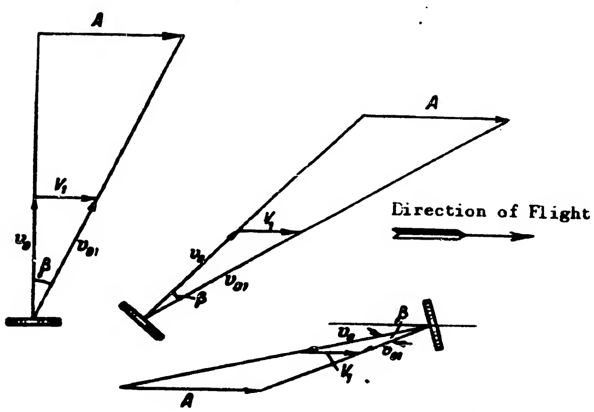

Fig. 81. Linear deflection does not depend on the angle-off of the weapon. The deflection angle varies with the angle-off of the weapon.

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It will be noted that so far we have examined only one aspect of the phenomenon under consideration, the variation in direction of release caused by the actual speed of the airplane. The other aspect of the problem results from the fact that actual speed also affects the magnitude of projectile velocity, and must therefore alter the shape of the trajectory.

We will now examine how actual speed affects trajectory form.

49. Effect of Actual Speed on the Form of the Trajectory

If the initial velocity of the projectile is decreased or increased, corresponding variations will occur in the time of flight of the projectile to a given range, and therefore the gravity drop, i.e. the curvature of the trajectory, will also vary.

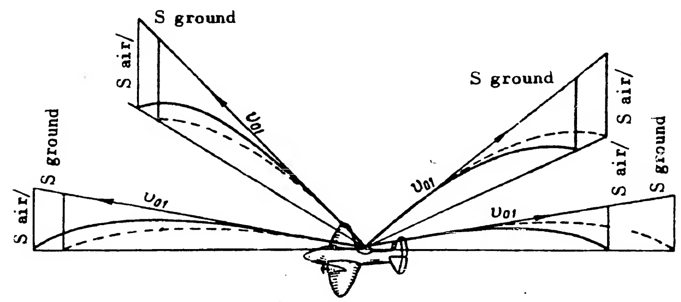

Fig. 82. Effect of actual speed and angle-off of weapon on form of trajectory.

In firing forward, the actual speed of the plane will be added to the initial velocity of the projectile, the projectile will travel greater distances in the air than it would in ground firing in the same time intervals, and drop as a result of

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gravity pull for the same distances as it would in ground firing. Therefore, the trajectory will flatten out, and the horizontal range for a given angle of fire will be greater.

In aft firing, if compared to firing on the ground, initial velocity is decreased by the airplane's actual speed, the projectile travels shorter distances in the same time intervals, and drops an equal amount. The trajectory of the projectile will have a more pronounced curvature, and the horizontal range of fire will decrease.

In firing at angles-off between 0 and 180 degrees, trajectories will assume forms intermediate between the most flattened and the most arched, while horizontal range will vary between the upper and lower extremes, decreasing when the angle-off of the piece is increased.

Thus, the actual speed of the gunner's plane gives rise to two new complicating factors which must be dealt with. The first is that values for gravity drop vary. The second is the fact that, even allowing for drop, one cannot set the weapon in the same plane as the target when firing, since projectiles will leave this plane.

Chapter VII

ALLOWING FOR THE EFFECT OF ACTUAL SPEED ON PROJECTILE TRAJECTORY IN AERIAL GUNNERY

50. Is it Possible to Estimate Projectile Deflection by Eye?

It is, of course, possible to do so. But what will be the accuracy of such an estimate, and can it be expected to lead to the hitting of the target which is being fired upon? It is possible, for example, to make an estimate of deflection on the basis of the definition previously given of the concept of "linear deflection". Linear deflection, as we have already seen, depends on range of fire, speed of plane and initial projectile velocity.

It is therefore possible to calculate in advance linear deflection for a

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certain range, say 100 m, and then allow more or less depending on whether the range of the target is greater or smaller than 100 m. Having determined the magnitude of deflection, it is possible, by using the target as a unit of scale, to carry the point of aim to one side of the target, in a direction opposite to that of the motion of one's own plane, to the required number of target scale units.

Let us assume, for instance, that deflection at a range of 100 m equals 15 m, and that the target fired upon measures 10 m, and is situated at a distance of 400 m. A range of 400 m is four times 100 m. Therefore, deflection for that range will likewise be four times that for a range of 100 m, i.e. will equal $15 \times 4 = 60$ m. The target measures 10 m, which means that linear deflection will equal $\frac{60}{10} = 6$ target diameters. Consequently, by setting backward the point of aim by 6 target diameters away from the target in a direction opposite to the motion of our own plane, we will make allowance for projectile deflection.

It would also be possible to make use of the deflection angle to introduce the necessary correction in sighting. That, however, would be even more difficult.

The example given above will suffice to show that, in sighting, even a well trained gunner would need a certain amount of time to carry out the calculations and aim his gun.

Since the gunner in aerial combat needs to solve yet another series of problems, it is worth examining the question of whether it is possible to remove the need for the gunner to allow for his own actual speed. This is the question we will now proceed to examine. At the same time, we will study a means of allowing for the variation in magnitude, and not only direction, of absolute initial projectile velocity.

51. How to Allow for Own Actual Speed in Aerial Gunnery

When we had to make an angle between the bore axis and the sight axis in the vertical plane to allow for gravity drop, we created a difference in elevation

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between the sight post and the pipper of the ring sight in relation to the bore axis.

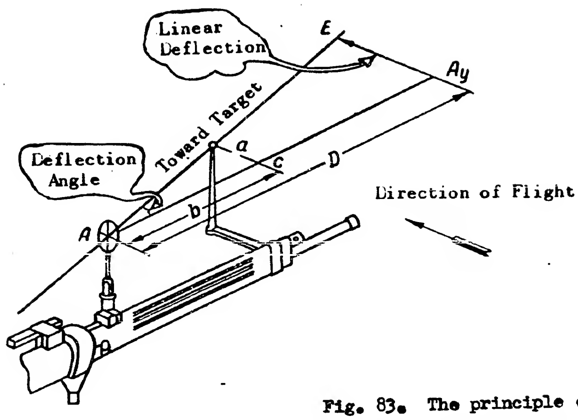

Fig. 83. The principle of reckoning projectile deflection by shifting over bead in the direction of own flight.

To create an angle between the sight axis and the bore axis in the horizontal plane to allow for projectile deflection, it is obviously sufficient to move laterally either the sight post or the sight ring. Let us assume we have shifted the sight post laterally from the bore axis in the direction of flight. If we now aim at the target through the pipper of the ring and the bead on the sight post, the bore of the gun will be pointing to one side of the target, in a direction opposite to the motion of the airplane.

It is obvious that to obtain the require angle of declination of the bore axis from the line of sight, the sight post must be moved laterally a certain specific distance. To find this distance, it would be necessary to find linear deflection for some particular range, and then shift the sight post forward in the direction of flight to a distance smaller than the obtained value for linear deflection by as many times as the distance from pipper to bead is smaller than the range for which

deflection was computed.

In practice, a much simpler and more convenient operation is performed (Fig. 84). The distance AC from the pipper of the ring to the axis passing through the place of attachment of the sight post to the barrel of the gun is taken as equal, at a particular scale, to the vector of relative initial projectile velocity v_o.

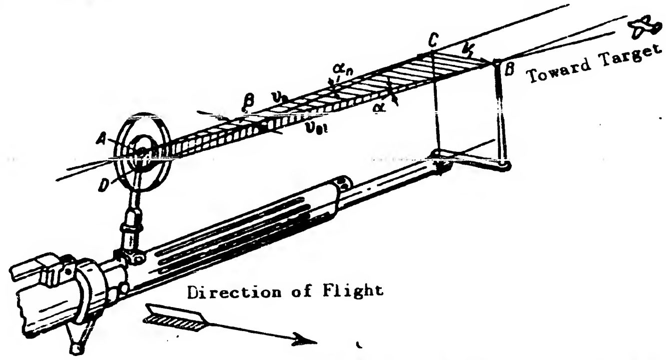

Fig. 84. The principle of reckoning actual speed and gravity drop of projectile by means of a vectorial device.

This is permissible since the orientation of this vector coincides with that of the gun bore, while the scale at which it is represented may be selected arbitrarily. If then, at this same scale, we take distance CB from the sight post attachment axis to the axis of the sight post itself as equal to the actual speed of the airplane, right line AB connecting the centers of the ring and the sight bead will be equal in magnitude (at the selected scale) and orientation to the vector of absolute initial velocity v_{o1}. Our problem is precisely to direct the vector of absolute initial velocity at the target when sighting. Therefore, when we sight at the target through the pipper of the ring and the sight bead, we are at the same time pointing at the target the vector of absolute initial velocity, while the bore of the piece has a declination away from the target to the side opposite to that of

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the motion of the plane, precisely equal in angle to the angle of deflection.

The sight we have just designed possesses one important drawback: when the gun swivels, the orientation of vector V_1 will fail to coincide with that of the true vector of the plane's actual speed, and the triangle of velocities ABC, and hence the deflection angle β, will remain unchanged, which of course should not occur, since the angle of deflection varies when the angle-off of the gun is varied, as a result of the deformation of the triangle of velocities. This means that, in order for our sight be genuinely useful for any position of the gun and to make a correct allowance for deflection, it is necessary that vector V_1, i.e. the post bearing the bead, be always parallel to the vector of the plane's own speed, or, in other words, the fore and aft axis. Then the angle of deflection would automatically be formed for any position of the gun, and the line of sight passing through the pipper and the bead will always have the same orientation as the vector of true absolute initial projectile velocity. There are several ways of keeping the vector

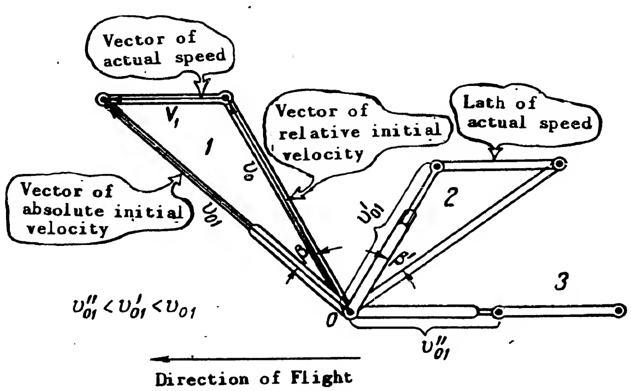

Fig. 85. The automatic variation of the value and orientation of the vector of absolute initial velocity in a vectorial sighting device.

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of the plane's own speed parallel, within the triangle of velocities, to the fore and aft axis of the plane. We will examine them subsequently. For the moment, to fully convey the cleverness of the design of the device described by us, we will note yet another of its features: its ability to make an allowance not only for changes in the orientation of the vector of absolute initial velocity, but also for its magnitude.

To have the bore axis at the angle of sight to the sight axis, boresighting involves the elevation of the ring pipper to a greater height above the bore axis than the sight bead.

In our diagram (cf. Fig. 84), the boresighted angle of sight, computed for fire from a stationary airplane, will be the angle ACD $= \alpha_p$. In aerial fire, we sight at the target along line AB, i.e. at an angle of sight ABD $= \alpha$, which will vary when the distance AB is varied.

If AB increases, this means that the absolute initial velocity of the projectile increases, and, consequently, the range of fire increases. But as distance AB increases, the angle of sight α diminishes, and thereby a correction is introduced for the increase in projectile velocity, since as the sight angle diminishes, the range of fire likewise decreases. In the end, range is maintained.

Thus, by using the sight described above, we allow the gunner to forego making an allowance for gravity drop, for projectile deflection, and for variations in the magnitude and direction of absolute initial velocity. All these problems are solved by the sight.

These very same problems may be solved by making mobile not the sight post, but the sight ring. However, the latter, to make an allowance for the airplane's actual speed, will have to be moved laterally in a direction opposite to that of flight.

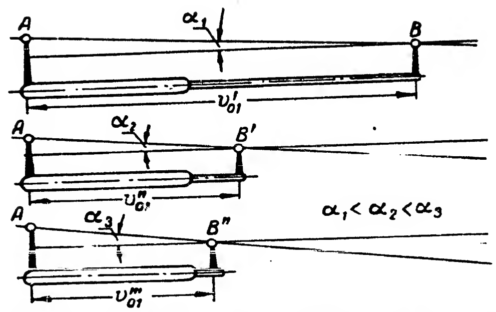

Fig. 86. Automatic setting of angle of sight by means of a vectorial sighting device

52. How the Indicator Lath of Actual Speed in the Vectorial Sighting Device Is Maintained Parallel to the Fore and Aft Axis of the Airplane

In the course of firing in aerial combat, the piece may assume the most varied positions: it may have to swivel from one side to the other, incline upwards or downwards, or, in ring type installations, be directed both fore and aft.

In all these maneuvers, it is imperative, in order to make correct allowances for deflection and variations in absolute initial velocity as the angle-off changes, to stabilize the vector of actual speed in the sight, i.e. to maintain it in a position parallel to the fore and aft axis of the plane for all turns of the gun.

The simplest and most clever device for this purpose is a mechanism for the stabilization of the vector of actual speed in the form of a vane-type sight post.

The vane-type sight post consists of a vertical pin, fixed on the end of the barrel, and the sight post proper, which is connected to the pin by means of two parallel bars. The lower bar is extended beyond the pin, spliced into two parts, on the ends of which are attached two box-shaped stabilizing surfaces. The bars are connected to the pin in such a manner that the sight post may swivel freely

around the pin and move upward or downward in relation to it, while always remaining parallel to it. The distance from pin axis to sight post axis equals the vector of own actual speed at the selected scale. When the plane is in motion, the oncoming air current acts on the fins of the sight, and the sight is carried forward, its position being rigorously determined by the air current. In this manner, whatever the orientation of the piece, the sight post is always set forward in the direction of flight.

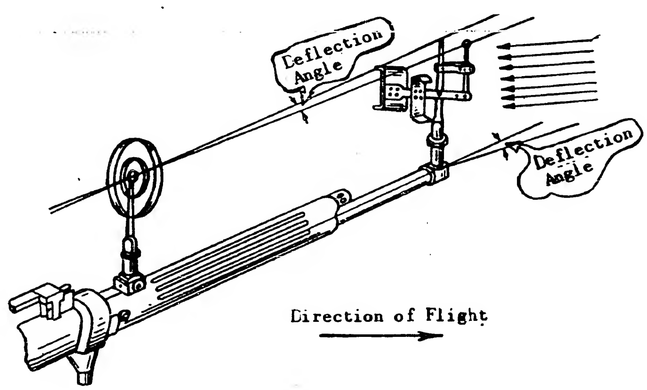

Fig. 87. Stabilizing the vector of actual speed by means of a vane-type sight post.

This highly original device, despite its extreme simplicity and seeming efficiency, has two important disadvantages. The fact is that the sight is oriented not parallel to the fore and aft axis of the plane or to the direction of its forward speed, but in accordance with air flow. Air flow, however, is highly variable and is warped by various bodies which happen to be in its way. The turret itself bearing the piece with its vane-type sight post distorts air flow around the airplane. What is more, the contours of the fuselage are not parallel to the fore and

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aft axis, and therefore neither is the air current. The screws of the plane also warp air flow. Consequently, the vane-type sight post, oriented strictly by air flow, does not indicate the direction of motion of the plane, and therein lies its main disadvantage. Another, less important drawback is that the sight represents a vector of actual speed which remains constant in magnitude, while the speed of the airplane, depending on the particular assignment being carried out, may vary significantly. If the speed of the plane differs from that used as a basis in adjusting the sight, the latter will introduce incorrect allowances for deflection and for the variation of the vector of absolute initial velocity.

In the more efficient sights, the vector of actual speed is made variable, while its stabilization is accomplished by mechanical, rather than aerodynamic means as in the vane-type sight post.

So as to make the vector of own speed variable within limits, the sight post or the ring are set not on a base of definite length, but on a special indicator lath which may be made to slide forward or backward in the grooves of a guide rule. The

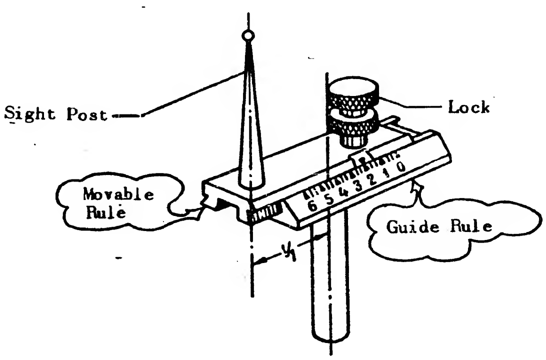

Fig. 88. Actual speed indicator lath

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lath itself bears a pointer, while the side of the guide rule is graduated to show own speed at the scale of the sight. This lath is termed the actual speed indicator lath. The guide rule is attached horizontally to a shaft, by means of which the rule is oriented along the fore and aft axis of the plane.

When the pointer of the lath is at zero on the graduated scale, the axis of the sight post is in line with that of the guide rule shaft support, and the position of the sight post then corresponds to ground fire conditions, when actual speed equals zero. For aerial fire, the lath pointer is set at the graduation corresponding to the speed at which the given assignment is to be carried out. In this position, the distance between the sight post axis and the axis of rotation of the actual speed indicator lath will equal the vector of actual speed at sight scale. It is now necessary to orient the lath in a direction parallel to the fore and aft axis of the plane, and to maintain it in that position for all positions of the piece. It would be possible to simply fasten it to the stationary turret ring in a position parallel to the fore and aft axis. However, it must be remembered that yet another vector enters into the triangle of velocities, and that this vector needs to be oriented in a specific direction: the vector is that of relative initial projectile velocity v_0. Vector v_0 must always be parallel to the bore axis, and therefore must be attached to the barrel. To get the vector of absolute initial velocity, it is necessary that the vector of actual speed originate at the extremity of the vector of relative initial velocity and, conversely, that the vector of relative initial velocity originate from the vector of initial speed. Therefore, if we secure the actual speed indicator lath to the airplane, while connecting the vector of relative initial velocity to the piece, and, at the same time, join these two vectors by means of a hinge, it will either be impossible to move the piece from its original position, or our vectorial mechanism will fail operate when the piece is turned. This means that both vectors must be connected either to the airplane or to the piece. Since the gunner operates his gun manually, it is preferable that he have

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the sight on the piece, and therefore that the entire vectorial device be connected to the latter. Consequently, it becomes necessary to employ special mechanisms to stabilize the actual speed indicator lath in such a way that, whatever the position of the piece, it remains parallel to the fore and aft axis of the airplane.

To maintain the actual speed indicator lath parallel to the fore and aft axis, use is made of vertical and horizontal stabilization mechanisms.

The vertical stabilization mechanism serves to keep the lath parallel to the fore and aft axis when the piece is moved vertically, while the horizontal stabilization mechanism holds the lath when the piece is turned horizontally.

The vertical stabilization of the actual speed indicator lath may be effected by means of an articulating parallelogram (Fig. 89).

Let us consider a parallelogram ABCD, made of articulating strips AB, AC, BD and CD. Strip AB is fastened to the turret in such a manner that it may only turn on the vertical axis passing through points A and B, while strip AC is fixed to the barrel of the piece. The actual speed indicator lath is fastened in a position perpendicular to strip CD and parallel to the fore and aft axis. Let us now agree to use the terms "vertical" and "horizontal" with reference to an airplane in level flight.

When the bore is moved in the vertical plane, strips AC and BD will also move in the vertical plane. Strip CD, to which the actual speed indicator lath is joined, remaining all the while parallel to fixed strip AB, will remain vertical and, therefore, the actual speed indicator lath will remain horizontal regardless of the deviations of the gun in the vertical plane.

Any turn of the piece on the vertical axis will be accompanied by a turn of the entire parallelogram in the horizontal plane. Consequently, the lath will remain horizontal, though its orientation within the horizontal plane may vary, unless measures are taken to stabilize it in the horizontal plane as well.

Another means of vertical stabilization is to connect the actual speed indicator lath to the barrel of the piece by means of three cylindrical gears (Fig. 90).

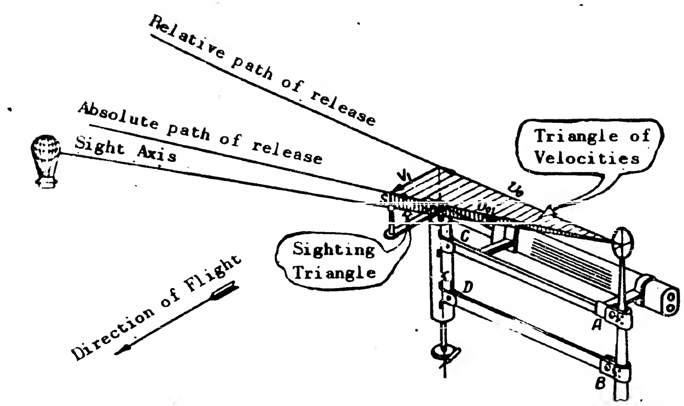

Fig. 89. Vertical stabilizing of vector of actual speed by means of articulating parallelogram.

Gear A is stationary in relation to the turret. Gear B, connected to gear A by a rod, engages with A. Gear C, engaged with gear B and connected to A and B by the rod,

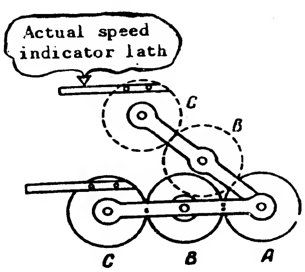

Fig. 90. Vertical stabilizing of vector of actual speed by means of gear device.

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will rotate in a direction opposite to that of B when the latter rotates. The rod AC, tied to the piece, turns with it in the vertical plane. The vertical shaft on which the lath turns is connected to gear C (or to its shaft). When the piece turns in the vertical plane, gear B, engaging gear A, turns gear C and with it, the lath, in a direction opposite to that of the motion of the piece and to an equal angle, as the diameters of the gears are equal to one another. Consequently, the lath remains in a horizontal position regardless of the position of the piece in the vertical plane.

To maintain the actual speed indicator lath parallel to the fore and aft axis of the airplane when the piece turns in the horizontal plane, similar mechanisms may be used. For this purpose, the barrel of the piece must be connected to two parallelograms, one vertical, the other horizontal. Then, whatever the orientation of the piece, the actual speed indicator lath will always be horizontal and parallel to the fore and aft axis, while the sight post will be vertical.

It is feasible to connect two parallelograms to the piece only when the gun is installed on a pivot support, i.e. when the points of support of the weapon do not move in relation to the airplane.

In turret installations, in which the piece moves horizontally with the turret at all points, such a simple means of horizontal stabilization is impossible. In such case, what is used is either a gear system or a flexible shaft. The use of a flexible shaft simplifies the design.

To stabilize the actual speed indicator lath when the piece is shifted horizontally, an indentation is made on the stationary ring of the turret, along which a gear moves when the mobile ring rotates, and the gear transmits its rotation to the flexible shaft. The actual speed indicator lath is fixed rigidly to a worm wheel, while the flexible shaft is connected to a worm shaft. When the turret rotates, the worm shaft turns the worm wheel, together with the speed indicator lath, in a direction opposite to that of the rotation of the turret, while leaving the

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lath parallel to the for and aft axis.

We will content ourselves for the moment with this description of the general principles of the stabilization of the actual speed indicator lath, since we will have occasion to return to the subject when describing aerial sights.

Thus, we have managed so far to overcome, more or less sucessfully, all the difficulties we have encountered, without burdening the gunner with a single complex problem when firing upon stationary targets. His skill so far needed to consist only in correctly aiming the sight axis onto the target. The remaining problems are taken care of by the sight.

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Chapter VIII

EFFECTS OF ALTITUDE AND POSITION ANGLE ON TRAJECTORY FORM AND HOW ALLOWANCE IS MADE FOR THESE EFFECTS IN AERIAL GUNNERY

53. How Altitude of Firing Affects the Form of the Trajectory, and Should Allowance be Made for Changes in Flight Altitude in Aerial Gunnery?

One of the characteristic features of aerial firing, as we have already noted earlier, is that it takes place within a wide range of altitudes. The firing airplane may be close to the ground or at a distance of 12 to 15 km from its surface.

Air resistance depends on air density, and air density decreases with altitude. This means that, as the altitude of firing increases, air resistance diminishes and, by the same token, a projectile will travel further at a high altitude than it will at a lower one. Since the projectile will drop because of the pull of gravity for about an equal distance in equal time intervals at either altitude, the shape of the trajectory will be more flattened at the higher altitude than at the lower. As altitude is increased, the trajectory levels out and range of fire increases. To maintain constant the range at which the path of the trajectory crosses the sight axis, it is necessary to diminish the angle of sight as altitude is increased.

In practice, then, should the angle of sight be modified in accordance with flight altitude?

Calculation shows, and experience confirms, that the constant angle of sight given the gun is entirely adequate for hitting the target at all altitudes and all combat ranges, without any correction of the angle of sight being required.

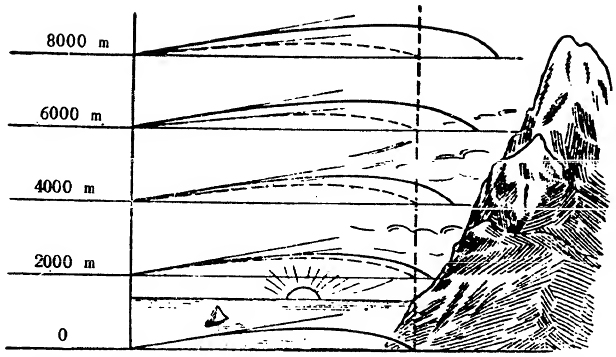

Fig. 91. Variation of trajectory form as a function of firing altitude. To maintain range, it is necessary to decrease sighting angle.

54. How Position Angle Affects Trajectory Form

We have also previously had occasion to note another special feature of aerial firing, which is that fire is not generally directed at a target in the same horizontal plane as the one in which the attacking airplane is situated, but may be either above or below it.

When the angle of position varies, the form of the trajectory changes more significantly than it does with altitude. This is explainable by the fact that the pull of gravity affects differently a projectile released at a small angle to the horizon than it does one released at a larger one.

If the projectile is travelling at an angle to the horizon, the force of gravity acting on the center of its mass may be seen as consisting of two component forces: one oriented along the axis of the projectile, and the other perpendicular to it. The component which is perpendicular to the axis of the projectile acts to curve the path of the projectile, and the greater its magnitude, the more arched is the path.

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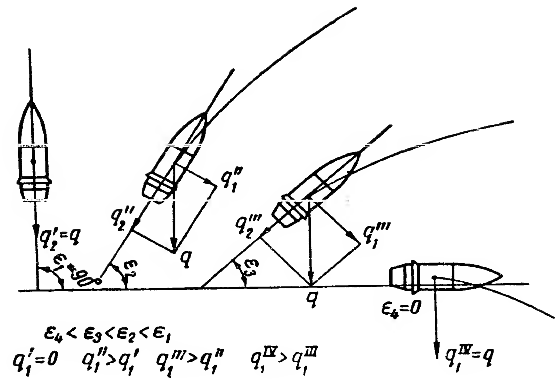

Fig. 92. As the angle of position decreases, the gravity component increases and causes curvature of trajectory of projectile.

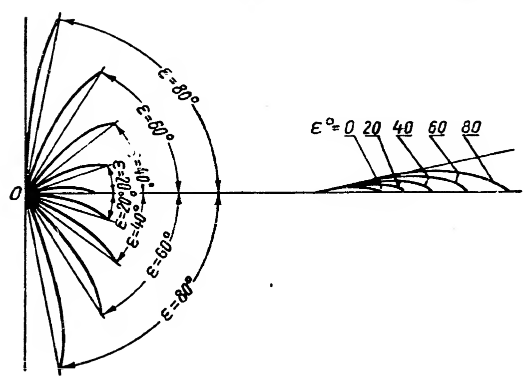

Fig. 93. As the angle of position increases, trajectory flattens and firing range increases.

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When a projectile is released upward vertically, the entire pull of gravity is directed along the axis of the projectile, and the component perpendicular to that axis is lacking. There is therefore no force to produce curvature, and the trajectory of the projectile will be rectilinear.

When the projectile is released horizontally, the entire pull of gravity is directed toward curving the path of the shell, and the curvature of the trajectory will be at its most pronounced.

The more pronounced the curvature of the trajectory, the smaller the distance at which it will cross the sight axis. This means that as the angle of position is increased, the trajectory will tend to cross the sight axis further, and will rise higher above the sight axis and line of sight. It will be noted that, since there exists an angle between the bore axis and the sight axis, and that the bore is oriented upward in relation to the sight axis, directing the sight axis vertically upward will cause the projectiles to travel backward over the gunner's head. To maintain the range at which the trajectory crosses the line of sight or the sight axis when angle of position increases, it is necessary to decrease the sighting angle.

The problem of introducing the necessary correction for variations in position angle may, of course, be handed to the gunner, but we will attempt to find a solution for it in another way.

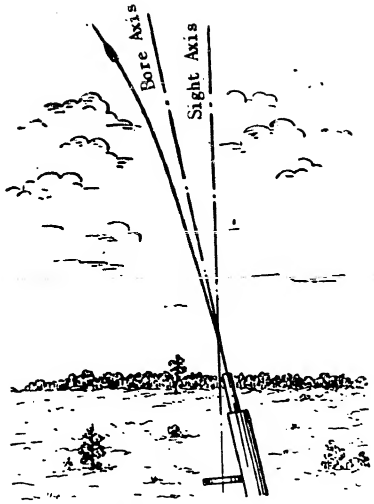

Fig. 94. If the sight axis of a boresighted piece is directed vertically upward, the projectile will travel backward over the gunner's head.

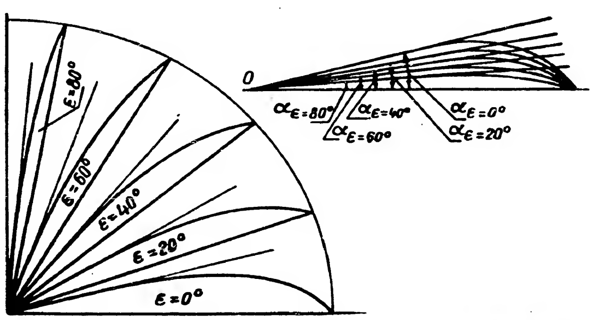

Fig. 95. To maintain range while increasing the angle of position, it is necessary to decrease sighting angle.

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55. How Allowance Is Made for the Effect of Variations in the Angle of Position in Aerial Gunnery

The effect of variations in the angle of position of the target is allowed for by means of a special device in the sight, which automatically corrects the sighting angle. To obtain a clear idea of the operation of this device, let us examine the

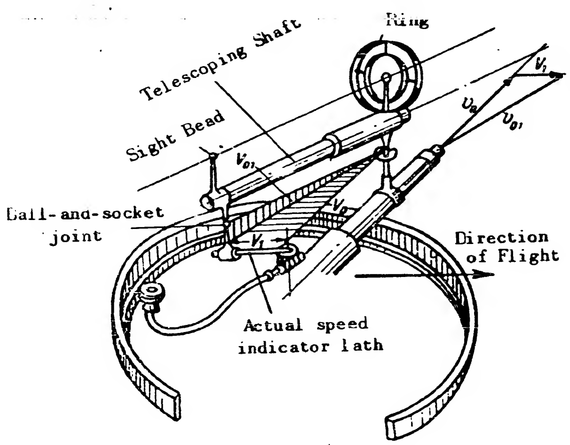

Fig. 96. Principle of design of PMP-6 sight.

design of the sight PMP-6.

A significant difference between this sight and others so far examined is the reversed position of the sight triangle and the triangle of velocities, i.e. actual speed is allowed for by moving not the forward end of the sight axis, but the aft end, and the sight post itself is situated aft of the sight ring. The sight post and sight ring are fastened to two telescoping shafts, so that the distance between the post and ring may be varied. The shaft to which the ring is fastened rests

on a socket, which allows its rotation both in the horizontal and vertical planes, whereas the shaft bearing the sight post rests on a ball-and-socket joint with which the actual speed indicator lath is provided. If the distance between the axis of rotation of the actual speed indicator lath and the vertical axis of the forward socket is equal, at a certain scale, to the vector of relative initial velocity, and if the distance between the vertical axis of the ball-and-socket joint and the axis of rotation of the indicator lath equals the vector of own actual speed, then the distance between the sight post and the ring will equal the vector of absolute initial velocity. When the piece turns in the horizontal plane, the indicator lath remains parallel to the fore and aft axis, being acted upon by a gear (engaging the cogs of the fixed turret ring), a flexible shaft and a worm transmission. In the process, the telescoping shafts come together or move apart, while the vector of absolute initial velocity is formed in the sight correctly, both in respect to magnitude and orientation. A special articulating parallelogram serves to stabilize the actual speed indicator lath when the piece turns vertically, maintaining the lath in a horizontal position. The support of the ball-and-socket joint, from whose center the distance to the plane of the triangle of velocities describes, at a specific scale, gravity drop for a given boresighting, thus always remains vertical.

The distance from the horizontal axis of the forward socket to the center of the ring, and that from the center of the ball-and-socket joint of the indicator lath to the center of the sight bead are equal. The sight bead is elevated above the plane of the triangle of velocities in such a way that an angle is formed between the sight axis and the bore axis, and that this angle equals the angle of sight.

When the sight axis is horizontal, the axis of the support of the ball-and-socket joint coincides with that of the sight post. The sight bead is then at its highest elevation above the bore axis, and the sighting angle then is at its greatest opening.

When the angle of position of the target increases, i.e. when the bore is in-

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clined upward, the telescoping shafts of the sight will rise and become inclined together with the bore, but since the support of the ball-and-socket joint remains vertical, the axis of the sight post will incline from the center of the ball-and-socket joint, the sight bead will approach the bore axis, sight elevation will decrease, and consequently, the angle of sighting will likewise diminish. When the bore is pointing vertically upward, the axis of the support of the ball-and-socket joint will be parallel to the bore axis, the ball-and-socket joint itself and the forward socket will be equidistant from the bore axis, sight elevation will equal zero, and the angle of sighting will therefore also equal zero. In such a case, the sight axis will parallel the bore axis.

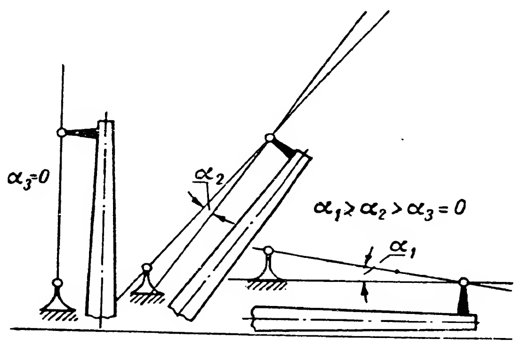

Fig. 97. Reckoning angle of position with sight of type PMP-6. Principle of constructing sighting angle for various angles of position.

For negative angles of position, the operation of the sighting mechanism will be the same, only the buckling at the ball-and-socket joint will be in the opposite direction.

In this manner, it is possible to build into the sighting mechanism the auto-

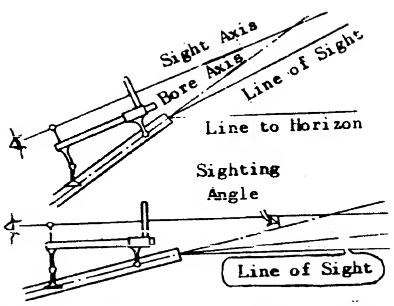

Fig. 98. Constructing sighting angle with with sight of type PMP-6.

matic decrease of the sighting angle corresponding to the increase of the angle of position. It may be shown mathematically that, for any given angle of position, the sighting angle formed by the sight will be the one required.

Thus, the new factor that had to be taken into account has not compli- ~~cated the job of the gunner, and the~~ sight has again solved the problem.

We have examined nearly all of the important factors affecting the velocity and the form of the trajectory of the projectile. We now know how to aim at a stationary target from an airplane in flight, how the sight allows for various factors affecting trajectory form, what factors are accounted for by boresighting the piece on the ground, and how boresighting is done. We will now proceed to find out how to fire on a real aerial target, namely, an enemy airplane. Such targets are in motion, and possess high velocities. These velocities must be taken into account, and while all the problems previously presented could be solved by means of the sight, now we will have to rely on the knowledge and skill of the gunner.

Chapter IX

HOW TARGET VELOCITY IS TAKEN INTO ACCOUNT IN AERIAL GUNNERY

56. General Features of Aerial Firing on a Moving Target. The Correction Triangle

At the beginning of the book, we noted those features that are peculiar to aerial fire, as opposed to ground fire, and the first of these was the high velocity of aerial targets.

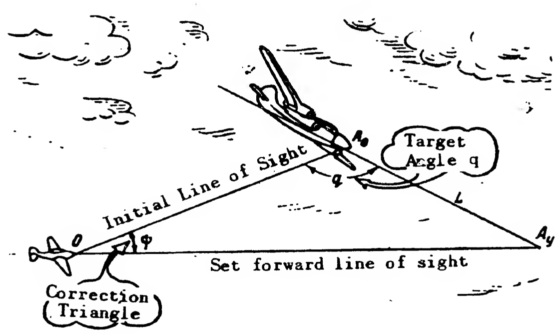

Fig. 99. Correction triangle.

This feature precludes the possibility of aiming and firing directly at the target, and makes it necessary to set forward the point of aim in the direction of motion of the target. This is called setting forward the aim on a moving target (Fig. 99).

At the moment of firing, the gunner sees the target in direction OA, at a distance of D_o. Point A_o, at which the target is situated at the moment of firing

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is called the initial point, and the distance to the target $OA_o = D_o$ is termed the initial range. To set forward the point of aim, it is very important to consider the direction of target motion relative to the gunner. This direction is fully determined by the angle formed by the course of the target A_oA_u, i.e. the path followed by the target, and the line of aim to the target OA_o at the moment of fire. This angle is called the target angle, and is designated by the letter q.

In the interval that the projectile is in flight, the target will have had time to move a certain distance $A_oA_u = L$. Point A_u, at which the projectile hits the target, is called the future position or set forward point, while the distance A_oA_u, covered by the target while the projectile is in flight (the distance between the initial point and the set forward point) is called the linear lead. Line OA_o, connecting the point of release O to the initial point is called the initial line of sight, while line OA_u, connecting the point of release to the set forward point, is called the set forward line of sight.

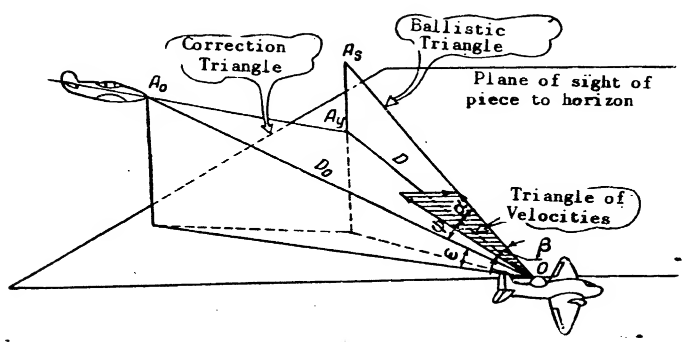

Fig. 100. General diagram of aerial firing.

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The triangle OA_0A_u, formed by the initial line of sight, the linear lead, and the set forward line of sight, is called the correction triangle.

The $A_0OA_u = \psi$, at which the gunner sees linear lead, or, in other terms, the angle formed by the initial and set forward lines of sight, is called the lead angle (Fig. 100).

To hit the target, it is necessary to set the piece at the moment of fire in such a manner that the trajectory of the projectile pass through the set forward point A_u. For this, it is required that the absolute initial velocity of the projectile be oriented along line OA which forms the angle of sight with the set forward line of sight.

We already know how the bore of the gun should be oriented in such a case.

Our basic problem is to determine the position of the set forward point.

57. How to Find the Position of the Set Forward Point

The set forward point is situated on the course of the target, or, in other words, on the prolongation of the target's axis. At what distance from the target does this point lie?

We already have some information on the subject. It lies at a distance from the target equal to the path traveled by the target during the flight of the projectile. This means that we have to know the velocity of the target and the time of flight of the projectile from the point of release to the point of impact. We do not know, as yet, how to find either of these. However, let us assume for the moment that we know target velocity. How will we find the time of flight of the projectile?

If the projectile traveled at a constant velocity, it would be simple to determine its time of flight, knowing the range. It would then be enough to divide the range of fire in meters by the velocity of the projectile in meters per second, to obtain the desired figure.

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However, the velocity of the projectile varies constantly, and the calculation of its time of travel is highly complex. The theory of aerial gunnery provides us with a way of finding the mean velocity of the projectile for a given range, which is, as we already know, that constant and imaginary velocity which would allow the projectile to cover a given distance in the same time interval as the projectile actually takes. Consequently, if we can determine the mean velocity of the projectile, its time of flight is easy to find, when range is known:

$$t = \frac{D}{v_{sr}}$$

Ground artillery disposes of a number of ways for determining range, but our task is complicated by the fact that what we need is the distance not to the target, but to the set forward point, for it is to that point that the motion of the projectile is directed, and it is by its range that the time of flight will be determined. We are seeking to find the position of the point of impact, and, for that purpose, we must know in advance the range to it, i.e., in other words, its position. This reasoning therefore leads us into a blind alley. Even if we know the distance at which this imaginary point was located in relation to the target, we would still not be in a position to determine its range.

The only way out of this situation is to take the range to the set forward point as equal to the distance to the target at the moment of fire, which we can determine. This, of course, introduces an error into the calculations, but there is no other solution.

Thus, having determined the range to the target and knowing the mean velocity of the projectile, we can find the approximate time interval of projectile flight. Now we may approximately indicate the position of the set forward point. If we represent the velocity of the target as v_{ts}, linear lead, i.e. the distance along the axis of the target from the latter to the set forward point will be

$$L = v_{ts}t$$

whence, by substituting for t the value $t = \frac{D}{v_{sr}}$, we get:

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$$L = \frac{v_u}{v_{ts}} D .$$

In calculations, either formula may be used, since there exist ready-made tables giving projectile time of flight for various ranges as well as mean projectile velocities.

Another way of finding the position of the set forward point may be indicated here: it is the angular method, based on the determination of the lead angle.

If we can find the opening of the lead angle, then, by inclining the sight axis from target direction at that angle in the direction of target motion, we will thereby be aiming it at the set forward point, and, firing from a boresighted piece, we will have the projectile pass through that point.

The lead angle is easily found from the well known theory of sinuses of trigonometry:

$$\frac{\sin \psi}{L} = \frac{\sin q}{D} .$$

Substituting $\frac{v_u}{v_{sr}} D$ for L, we get:

$$\sin \psi = \frac{v_u}{v_{sr}} \sin q.$$

The lead angle is generally not large, since linear lead is many times smaller than range of fire. Therefore, in accordance with trigonometric practice, it is possible to substitute for the sinus of this small angle the angle itself in rads, i.e. to write:

$$\psi = \frac{v_u}{v_{sr}} \sin q \ [\text{rads}].$$

Converting rads into mils, we get:

$$\psi^T = 1000 \frac{v_u}{v_{sr}} \sin q \ [\text{mils}]$$

The formula for the lead angle differs from that for linear lead in that sin q takes the place of D.

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58. Can the Gunner Determine Exactly and Use Linear or Angular Lead?

To answer this question, we must first find out what linear or angular lead depend on.

We have the following formula for linear lead:

$$L = \frac{v_u}{v_{sr}} D.$$

To find the value for linear lead in meters, we must know target velocity and the mean velocity of the projectile for a given range of fire in meters per second, as well as the range to the target in meters.

The gunner does not have the slightest possibility of determining target velocity, since he may observe only its relative displacement, and his estimation of both the magnitude and direction of this velocity will be incorrect. The mean projectile velocity depends on the range of fire, on the altitude at which the firing takes place, and on the absolute initial velocity of the projectile. The range to the target must also be found. It is understandable that the gunner is in no position to take all these factors into account and to calculate the desired linear lead.

For the lead angle, we have the formula:

$$\psi^{T} = \frac{v_u}{v_{sr}} 1000 \sin q.$$

This formula is even more complex, since in addition to having to determine all the values required in the linear method, it is necessary to find the target angle and its sinus.

Thus, we come to the conclusion that it is too much to expect of the gunner to find an exact solution to the problem of determining linear or angular lead, and that perhaps more approximate but simpler means must be sought to allow for target velocity.

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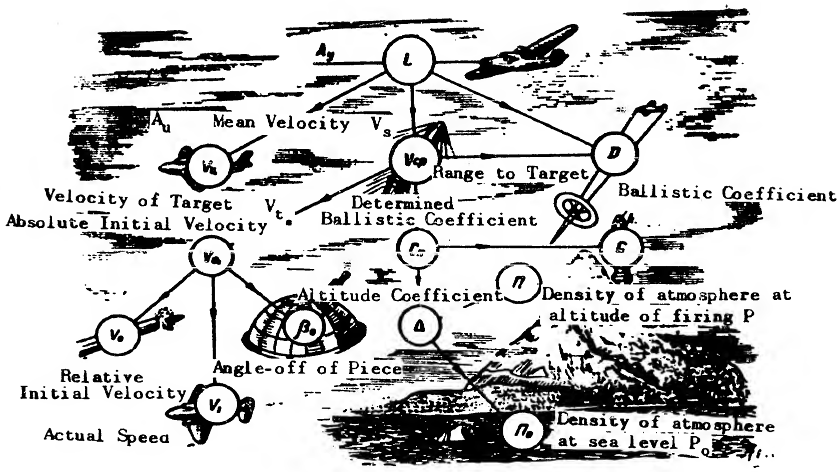

Fig. 101. Dependence of linear lead on various factors.

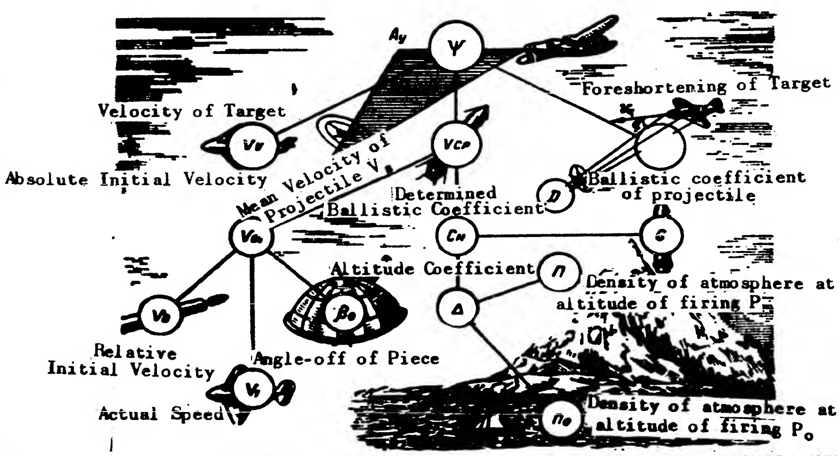

Fig. 102. Dependence of angular lead on various factors.

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It is this problem we will attempt to solve in the paragraphs that follow.

59. How the Problem of Sighting is Simplified in the Linear Method of Allowing for Target Velocity

A glance at the formula for linear lead might suggest that linear lead is directly proportional to range. However, this is not precisely correct. The mean velocity of the projectile forming the denominator of the formula, depends in turn on range of fire, and decreases as range is increased. Thus, for instance, if for a range of 100 m linear lead equals 30 m, for a range of 200 m it will be not 60 m, as one might expect if it were directly proportional, but somewhat greater, as result of a decrease in mean velocity. Therefore, it is said that, as range is increased, linear lead for a given target velocity increases in a progression, i.e. more rapidly than range. In practice, and at the ranges of aerial fire, this progression is negligible, and linear lead may be considered as directly proportional to range.

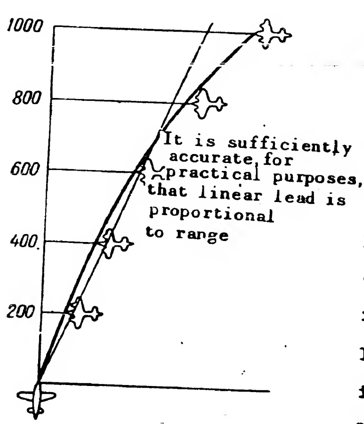

Fig. 103. Linear lead increases gradually as range is increased.

The effect of altitude on mean velocity, and therefore on the magnitude of linear lead, is negligible.

Target velocity, as we have already pointed out, cannot be determined exactly by the gunner. It has to be estimated from the type of aircraft to which the target belongs. Aerial combat, as a rule, takes place at maximum speeds. Therefore, if the maximum speed of a given enemy plane is known, it may be assumed that in aerial

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combat, it is traveling at that very speed.

This means that, to determine target velocity, the gunner must study enemy aircraft and know how to recognize their type and, consequently, their maximum speed.

The speeds of modern pursuit planes vary insignificantly from type to type. Likewise, the speeds of various types of bombers and transport planes differ little within each class. It is thus possible to assume, for example, that all fighters have speeds of 700 km/hr, all bombers speeds of 500 km/hr, and all transport planes speeds of 250 km/hr. The airborne gunner has then only to determine what class of aircraft he is going to fire upon, i.e. to find out whether the enemy plane belongs in the class of fighters, bombers or cargo planes.

Now that we have solved these particular problems, we may proceed to the matter of calculating linear lead.

Since we have agreed to consider linear lead as proportional to range, to categorize target velocities into three groups according to target type, and to neglect the effect of altitude on the magnitude of linear lead, we may solve the problem in the following manner.

We will calculate linear lead for each class of airplane for a range of 100 m, computing mean projectile velocity for a range of 100 m at an average flight altitude, for example, 4000 m. Then, once we know linear lead for each class of airplane at a range of 100m, it will be simple to compute it for any given range of fire. The lead to be allowed for in firing will be as many times greater or lesser than that for a range of 100 m as the range to the target will be greater or lesser than 100 m.

If, for example, when firing at fighters, linear lead for a range of 100 m amounts to 25 m, then at a range of 200 m it will be 50 m, at a range of 300 m, 75 m and so forth, i.e. as many times as 25 m as range is greater than 100 m, or as many times as one hundred meters occur in the range.

Now a new problem arises, that of setting forward in practice the future

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position to the distance away from the target that has been computed. The target may be situated at varying distances from the gunner, and the lead distance will vary in apparent size, seening greater as the range to the target is smaller, and smaller as the range is greater. In addition, the target may be moving in a direction perpendicular to the line of sight, or at any other angle in relation to it, i.e. the target angle may vary considerably. When the target moves perpendicularly to the line of aim, linear lead will be visible at its entire length; when it moves at angle, linear lead will appear shortened, and its seeming magnitude will seem less

If we have to estimate some distance, we always use some unit of measurement. In this case, the distance to be measured is far away from the observer. The measure we may use in this particular situation is the length of the fuselage of our target.

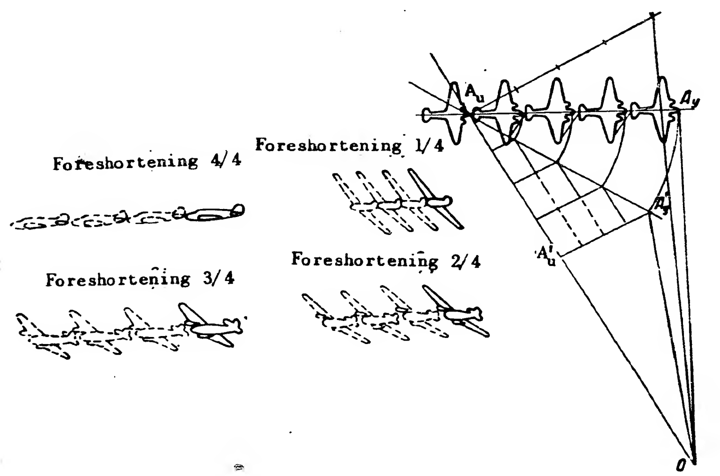

Fig. 104. The number of fuselage lengths to which future position may be carried is independent, for practical purposes, of the target's angle of position.

If, for example, the linear lead to be allowed for is 30 m, while the length of the fuselage of the target equals 10 m, we allow for the distance required if we carry the point of aim 3 fuselage lengths forward from the nose of the target along it's fore and aft axis.

It may be calculated in advance how many fuselage lengths the point of aim must be moved when firing at a range of 100 m at a given class of aircraft, and then this number of fuselage lengths may be increased or decreased for different ranges, depending on how many times the range of fire exceeds or is inferior to 100 m.

The angle of position of the target has no bearing on the problem when one is using this method, since the apparent length of the fuselage will decrease to the same extent as the apparent lead distance. Therefore, the apparent lead will contain the same number of apparent fuselages as when the angle of position equals 90 degrees. The sighting method whereby the set forward point is found by using the fuselage length of the target as a unit of measure is called fuselage ranging.

When firing at a range of 100 m, the following lead distances should be used for modern airplanes:

For jet fighters	3 fuselage lengths
For conventional fighters	2 fuselage lengths
For medium bombers	1.5 fuselage lengths
For transports	3/4 of a fuselage length.

Thus, in fuselage ranging, one must remember how many fuselage lengths to carry the point of aim when firing at a range of 100 m for each class of aircraft, and perform the following operations:

- determine the class to which the target belongs
- determine, in some manner, range to target in hundreds of meters
- multiply the number of fuselage lengths in the lead distance for that class of target and a range of 100 m by the number of hundreds of meters in the range

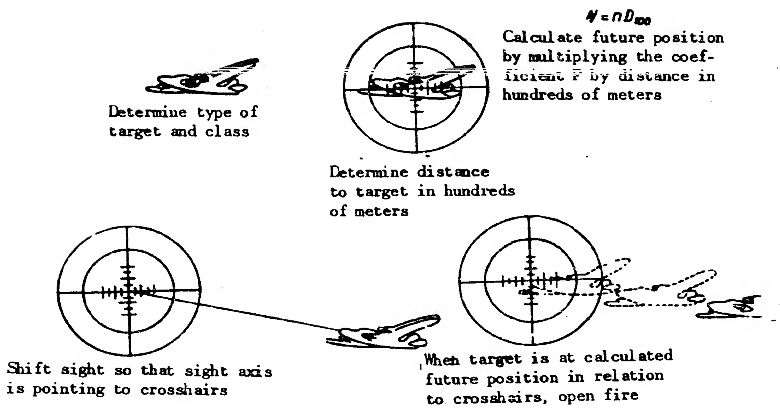

Fig. 105. Sequence of operations in fuselage ranging.

– using the size of the fuselage of the target as a unit of measure, carry out the point of aim along the axis of the target to the required number of fuselage lengths and open fire.

In fuselage ranging, the gunner must determine with the utmost accuracy the range to the target. An error in range determination of 100 m entails, when firing on a jet-powered pursuit plane, an error in lead estimate of 3 fuselage lengths, i.e. about 30 m, and, when firing on a bomber, an error of 2 fuselage lengths, i.e. again about 30 m. Good training is required to interpolate by eye the needed number of fuselage lengths.

As may be seen, this method of sighting is carried out entirely by eye. The gunner needs no auxiliary mechanisms to allow for the required lead. The axis of sight is simply aimed at the set forward point when it is located.

Aiming by eye involves, without doubt, large errors. For this reason, fuselage ranging is used only when the design of the sight does not admit of any other way.

Let us now examine some other methods of sighting.

60. How the Problem of Sighting is Simplified in the Angular Method of Allowing for Target Velocity

To find possible means of simplifying the problem of sighting in the angular method of allowing for target velocity, let us turn again to the formula for the lead angle:

$$T = 1000 \frac{v_{ts}}{v_{sr}} \sin q.$$

Classifying all aircraft into categories, as in the preceding section, we may compute in advance the member $1000 \frac{v_{ts}}{v_{sr}}$ of the formula for each class of aircraft for a given piece and for certain average conditions of fire.

When firing, it will be enough simply to multiply this given figure by the sinus of the target angle. But therein lies the complexity of the problem.

How is this problem solved?

In firing at a target, located at a given range, the magnitude of linear lead does not depend on target angle, and will be constant regardless of the direction in which the target is moving. However, the opening of the lead angle will vary and depend on the target angle. When the target angle equals 90 degrees, the lead angle will have its greatest opening, whereas at target angles of 0 and 180 degrees, it will equal zero. The smaller the apparent value of linear lead, the smaller the lead angle.

The sinus of the target angle characterizes the apparent shortening of linear lead for target angles differing from 90 degrees.

~~In discussing fuselage ranging, we already had occasion to state that the~~ apparent shortening of linear lead will be the same as the apparent shortening of the fuselage of the target. Therefore, we may say that the sinus of the target angle characterizes the apparent shortening of target fuselage length for target angles other than 90 degrees.

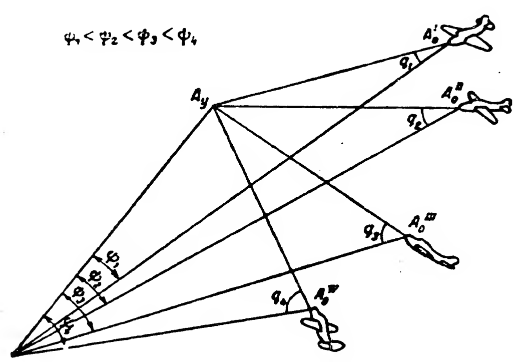

Fig. 106. The lead angle increases as target's position angle is increased from 0 to 90 degrees, then decreases.

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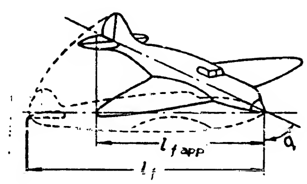
The apparent shortening of the fuselage of the target as a result of its inclination relative to the line of sight is called the foreshortening of the target. The numerical value of foreshortening is that of the sinus of the target angle.



$$l_{\varphi}\ \text{vid} = l_{\varphi} \cos(90 - q) = l_{\varphi} \sin q$$

$$l_{\varphi}\ \text{vid} \qquad \frac{l_{\varphi}\ \text{vid}}{l_{\varphi}} = \sin q$$

Fig. 107. The foreshortening of the target is the apparent reduction of the length of the fuselage as the result of its inclination relative to the line of sight.

Experience shows that the gunner may learn to determine foreshortening to an accuracy of 1/4 or, in other words, to estimate directly the sinus of the angle of target without having first to determine the target angle itself. What do we mean when we say "foreshortening equals 1/4"? We mean that the sinus of the target angle equals one quarter, which, in turn, indicates that the gunner sees one quarter of the length of the target fuselage. A foreshortening of 2/4 means that the gunner sees 2/4 , i.e. one half of the length of the target's fuselage, etc.

In the first case, the gunner sees the fuselage four times smaller, and in the second case, one half as large as it would normally appear. Therefore, to determine foreshortening it is enough to imagine the fuselage at its full length and then estimate what proportion of the actual length is visible.

Target foreshortenings of 0/4, 1/4, 2/4, 3/4 and 4/4 correspond, respectively, to target angles of: 0 and 180 degrees; 15 and 165 degrees; 30 and 150 degrees; 50 and 130 degrees; and 90 degrees.

This may be shown as follows:

sin 0 degrees = sin 180 degrees =	or 0/4
sin 15 degrees = sin 165 degrees = 0.295 ≈ 0.25	or 1/4
sin 30 degrees = sin 150 degrees = 0.5	or 2/4
sin 50 degrees = sin 130 degrees = 0.766 ≈ 0.75	or 3/4
sin 90 degrees = 1	or 4/4

Thus, to determine lead angle when firing upon aircraft belonging to any particular class of targets, it is necessary to estimate its foreshortening and to multiply the lead calculated in advance for that class of targets by the foreshortening . This gives the lead angle in mils.

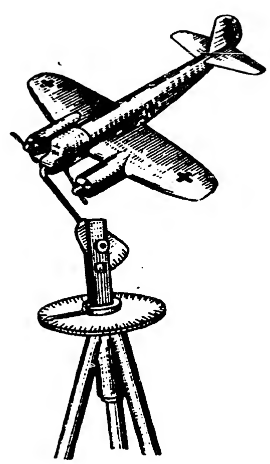
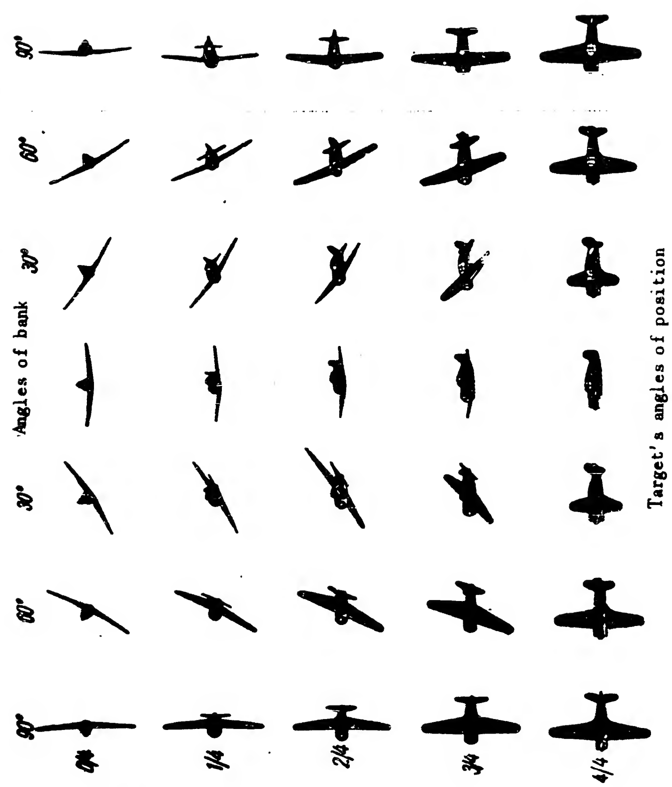


Fig. 108. Device used in training to determine foreshortening.

When using this method of sighting, the gunner is required to rapidly and accurately determine foreshortenings. This ability is acquired by lengthy and systematic training with the aid of special devices, which incorporate in their design airplane models which may be turned around so as to be seen with various foreshortenings. Special tables, drawn up for various types of enemy planes, may also be used to learn the appearance of various degrees of foreshortening.

We now know how to find the lead angle. How then shall we use this angle to move the point of aim relative to the target? The gunner obviously needs some kind of instrument to measure angles. This protractor, again, is built into the sight. Let us examine the principles used in

Foreshortened views



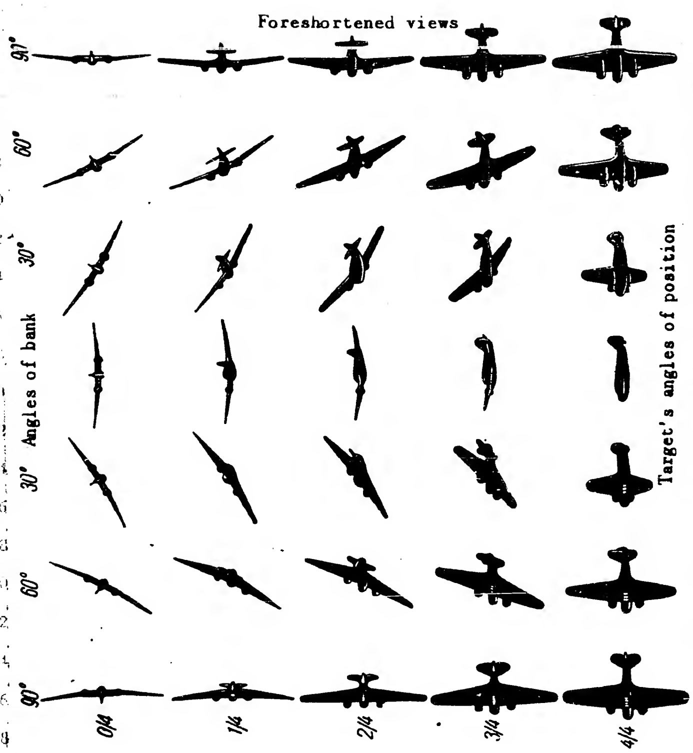


Fig. 110. Table giving foreshortened views of bomber plane.

61. Principles of Design of Aerial Ring-Type Gunsight

The required lead angle may be formed in two different ways.

The first is to use rules which are hinged together and made to slide over a graduated arc. The second is by means of a segment of arbitrary length, set in a direction perpendicular to the line of sight at an accurately determined distance. away from the eye.

Let us assume that, to form the lead angle, we are making use of the protracting device consisting of two rules. One of these is set parallel to the vector of

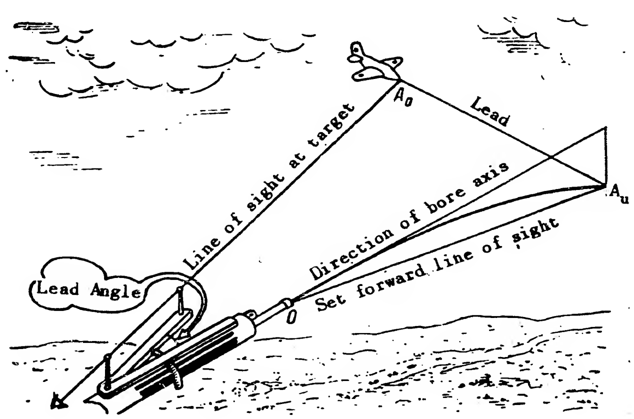


Fig. 111. Constructing lead angle by means of two rules.

absolute initial velocity by means of the vectorial mechanism of the sight, while the other may move away freely from it to the right and to the left. To this mobile rule is fastened a sighting installation consisting of a sight bead and a pipper. To allow setting the desire angle by means of the movable rule relative to the

fixed rule, the arc is graduated in mils.

If, when firing, we set the movable rule at an angle equal to the lead angle as determined, and orient it toward a target in level flight by means of the sighting installation, the absolute initial velocity of the projectile will be oriented to the set forward point. In this manner, by keeping the movable rule on the target, we may fire knowing that the projectiles will pass through the set forward point, on the condition, of course, that the piece has been boresighted, i.e. that the line of aim passing through the pipper and the sight bead is inclined downward and forms the sighting angle with the bore axis.

We have remarked that the required lead could be thus allowed for on the condition that the target be in level flight. It is also assumed that the gunner's own plane is in horizontal flight.

When fire is opened on the target, the latter's fore and aft axis may, in actuality, be oriented in any number of directions. The device described may be used if the plane containing the angle formed by the two rules may be set in such a way

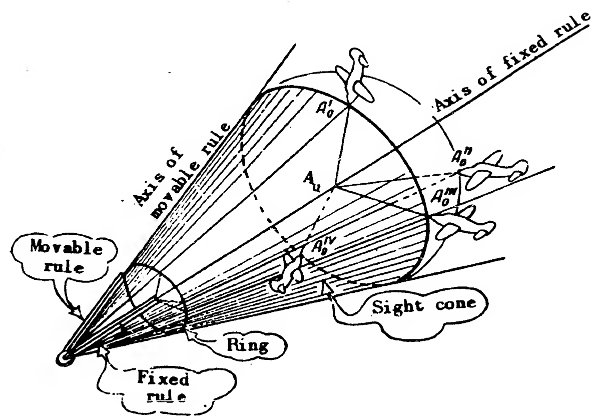


Fig. 112. Constructing the sight cone.

that the fore and aft axis of the target plane is in the same plane, i.e. the movable rule must be able to turn around the fixed rule as an axis. This rule will therefore describe a cone in space for any given lead angle and for varying orientations of target motion. This cone is termed the cone of sight. Since the movable rule is directed along the initial line of sight, while the fixed one coincides with the set forward line of sight, it may be said that the cone of sight is the cone described by the plane of the correction triangle rotating on the set forward line of sight. For each foreshortening of the target, the sight must construct a different cone of sight. Our hinged angle formed by two rules cannot completely solve the problem of sighting on an aerial target in motion, since as the movable rule turns, the pipper and sight bead will likewise become inclined, and the boresighting of the piece will fail to remain effective. For this reason, practice requires the use of another device, in which the segment of a right line, rather than an angle, is used as a measure of the lead angle.

As the movable rule rotates freely around the fixed one, its extremity describes a circumference around the fixed rule. The radius of this circumference equals the distance from the free extremity of the movable rule to the fixed one along a perpendicular to the latter.

If we now replace this imaginary circumference by a ring, and place the sight bead in the position of the hinge of the two rules, it is obvious that any right line connecting the sight bead to the circumference of the ring will be the generatrix of the cone of sight. In sighting, it will therefore be sufficient to set the piece in such a way that the target be on a straight line connecting the sight bead and the ring, and that its axis be oriented toward the center of the ring.

In the device we thus obtain, the radius of the ring becomes a measure of lead angle. The greater the radius of the ring, or the smaller the distance between the sight bead and the ring, the more open the angle formed by our device. This means that, for a given distance between the sight bead and the ring, the radius of the

ring will correspond to a definite lead angle.

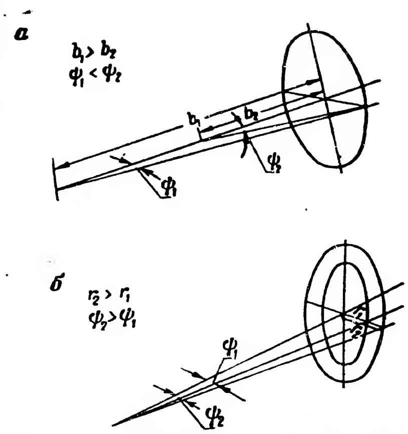


Fig. 113. Dependence of lead angle on sight base and radius of ring.
a – as sight base is decreased, lead angle increases; b – as radius of ring is increased, lead angle also increases.

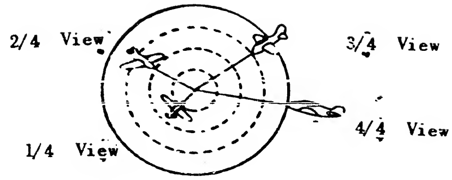


Fig. 114. Principle of sighting through ring sight.

It would be possible to compute in advance for each class of aircraft the lead angles corresponding to 1/4, 2/4, 3/4 and 4/4 foreshortened views, and set up four concentric rings for these angles in such a way that each ring correspond to a particular foreshortening. In sighting, it would then be enough to determine the foreshortening of the target and to set the target on the corresponding ring, while orienting its axis toward the ring's center. This would solve the problem of allowing for target velocity. But even if all targets are divided into two classes the sight would have to contain 8 rings. These rings would crowd the field of vision, and the gunner would be in danger of confusing the purpose of each one of

the rings.

In practice, things are done otherwise. For each class of targets, one ring is provided, corresponding to a foreshortening of 2/4. If the target is seen in a 1/4 view, the target is set at half the radius of the corresponding ring. If it is seen at 4/4, the target is set outside of the ring, at a distance equalling one ring radius. Finally, if the target appears in 3/4 view, it is also set beyond the ring, but at a distance of one half of the ring radius.

Ring sights generally have two rings. One of these is intended for sighting on

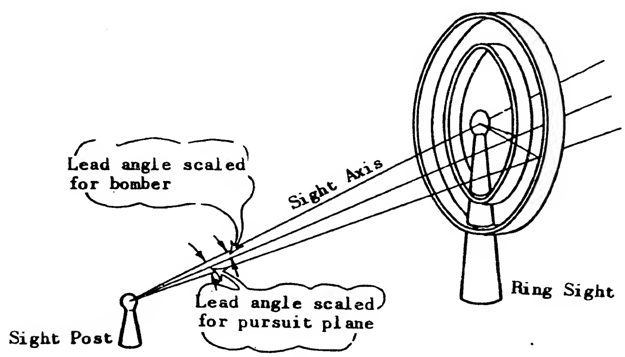


Fig. 115. General diagram of mechanical ring sight.

bombers having speeds of 400 km/hr; the other is intended for sighting on pursuit planes with speeds of 600 km/hr.

The leads allowed for the velocities of these targets and, therefore, the radii of the rings, are computed for certain average conditions of fire and a definite absolute initial projectile velocity. We will become acquainted with the rules and techniques of sighting in Chapter XI, where we examine the design of certain aerial sights.

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Chapter X

FIRING ON GROUND TARGETS FROM THE AIR

62. How the Velocity of the Ground Target Is Taken into Account

Ground targets are possessed of considerably smaller velocities than aerial targets, but they are usually fired upon at greater ranges. Ranges of fire on ground targets are usually between 600 and 1200 m, and are therefore approximately twice as large as those involved in aerial fire. In firing from strafing or pursuit aircraft, the piece is aimed with the body of the airplane and the plane flies straight at the target. In aerial combat, pursuit planes usually attempt to approach the target from the rear, come within as close range as possible, and then only open fire. If a fighter is successful in executing this maneuver, he has sufficient time for firing, since the attacker and the attacked are moving in the same direction, and the gain of the one on the other is negligible. When firing from a bomber at an attacking fighter, the gunner likewise has sufficient time to aim and fire. An exception to this is fire from opposite courses, when, in order to fire for as short a time interval as one second, a modern interceptor must open fire at a range of 2500 to 3000 m.

When firing on a ground target, the pilot directs his plane at the target and dives at it; the target and the ground move toward him at the speed at which his plane is diving. If the plane has a speed of say, 150 m per second, then each second spent in aiming and firing brings the plane 150 m closer to the target. Furthermore, to bring the plane out of the dive, it is necessary to have available a reserve of altitude of 200 to 300 m, since, on coming out of the dive, the airplane loses altitude and, if the reserve is insufficient, runs the risk of colliding with the ground. Therefore, if the plane began its dive on the target from a range of, say, 1500 m, its guns will be bearing on the target for only 900 to 1000 m,

which he will cover in 6 to 7 seconds. In that time interval, he will have to sight, fire a salvo, introduce corrections on the basis of tracers and points of impact, and fire the salvo which will strike the target. At the moment he ceases fire and comes out of the dive, he will be separated from the target by a distance of 400 to 500 m. For this reason, fire upon ground targets must be opened at considerable ranges.

The greater the range, the longer the time of flight of the projectile and the longer the distance traveled by the target in that interval.

If the target moves even at the relatively low velocity of 10 m per second, and if the time of flight of the projectile is of only 1 second, the target will have had time to move 10 m from its initial position.

This means that an allowance must be made for target velocity in air to ground fire.

Allowance for ground target velocity may be made on the same principles as that for aerial targets. It should be pointed out at the outset that the angular method of allowing for ground target velocity is difficult to apply under combat conditions because the lead angle, in air to ground fire, depends on the angle of dive, and the latter may turn out to be quite different from the one intended before the attack. For this reason, the angular method of sighting may be recommended for fire only on ground targets of a type which may be approached by the pilot at an altitude already determined in advance, and attacked at an angle of dive known beforehand, i.e. only when the lead angle may be computed in advance.

In firing upon ground targets, fuselage ranging is generally used. Lead for target velocity is found in the same manner as when firing upon aerial targets, i.e. if target velocity equals v_{ts} and the time of flight of the projectile is t, linear lead for that velocity will be:

$$L = v_{ts}t.$$

The dimensions of the target are again used to scale linear lead. If the

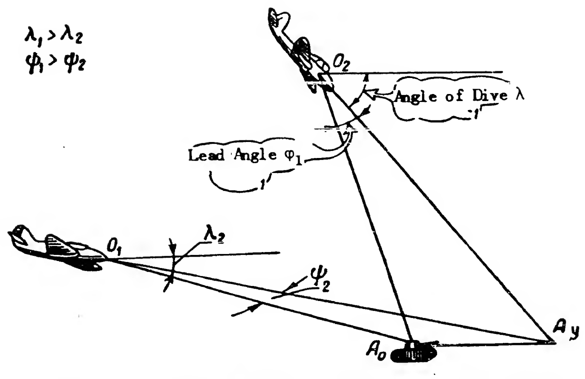

Fig. 116. When firing at ground targets, lead angle depends on the angle of dive.

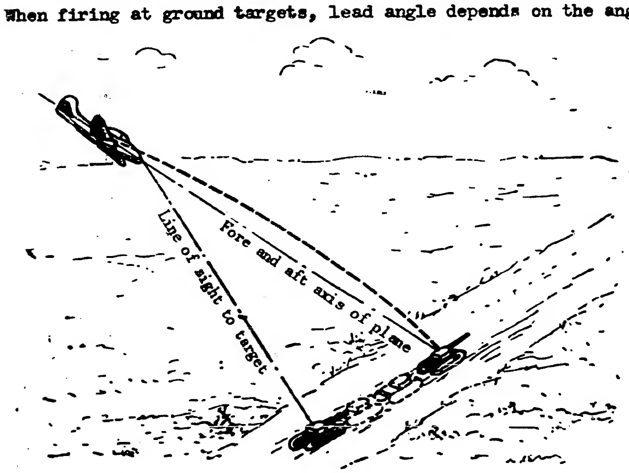

Fig. 117. The velocity of a ground target when firing from the air is allowed for by fuselage ranging.

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length of the target equals l, lead may be expressed as follows in terms of target dimension:

$$n = \frac{L}{l} \quad \text{or} \quad n = \frac{v_{ts}t}{l}$$

Lead is calculated for the range at which fire is opened, i.e. maximum lead is allowed for at the initial moment of fire, and is progressively decreased in the course of the attack, corrections being made on the basis of shell traces and visible impacts.

Lead in units of target size for a given range, when the target is known, may be computed in advance before take-off. When attacking, fire should be then opened at that range.

63. Allowance for Wind in Fire on Ground Targets

In aerial fire upon an airborne target, wind is of no significance. In air to ground fire, it is an important factor. If wind velocity is represented as U, the linear deflection of the projectile C at the target will be:

$$C = Ut.$$

Consequently, the point of aim must be carried into the wind to that distance to have the projectiles hit the target. To compute correction for wind, target size is again used as a unit of scale.

To allow both for target and wind velocity at the same time, the point of aim is first carried forward along the direction of motion of the target to a distance equalling linear lead; then the sight axis is shifted windward to the correct deflection distance. Target size is used as a unit of measurement in both cases.

Chapter XI

AERIAL RING-TYPE GUNSIGHTS
THEIR DESIGN AND OPERATION

64. Principle of Design of Collimator Sight

An aerial gunsight is a complex and accurate instrument, combining mechanical and optical mechanisms and devices for reckoning with the ballistic properties of projectile trajectory, own actual speed, and the effects of angle of position and target velocity. In the course of their evolution, gunsights have incurred radical changes, and the sights currently used differ greatly in design from those first developed in aviation.

We will examine here only some of the sights used at the time of the second world war. Among the most widely used in the air force are collimator gunsights. Before proceeding to examine the design of the instrument as a whole, let us outline the principles underlying the design of the collimator sight.

The basic part of any sighting instrument is the device indicating the axis of sight. As we have already seen, it is precisely in relation to this axis that the piece has to be set at the required angles in the vertical and horizontal planes to ensure the passage of the trajectory through the set forward point when the sight axis is directed at that point.

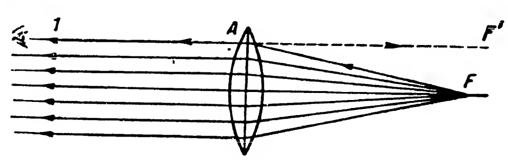

Fig. 118. The passage of light rays through a lens.

The sight axis may be provided by means of a mechanical device or optically. We are already acquainted with the simplest iron sight consisting of a sight post and a ring with a pipper. Let us now see how it is possible to provide a sight axis or line of sight by means of an optical device.

Let us take a biconvex lens and place a point source of light at its focal point. Since, as the reader probably already knows, the focal point is the point at which all light rays converge after their refraction through the lens, if they are directed at the latter in the form of a parallel beam. If the rays originate at the focal point they will emerge from the lens in the form of a parallel beam following refraction(Fig. 118). If the eye is placed on the other side of the lens, and we look through the lens, a very narrow beam of all the light rays issuing from the lens will strike the eye, and we will see the focal point F in the direction from which this beam will have reached our eye. If the eye is placed in the position shown in Fig. 118, it will see point F at infinity on the prolongation of line 1A. This means that the image of point F that the eye sees determines the position of a specific line of sight 1A, and that, if we place some object in the same position as luminous point F, we will be orienting the line of sight 1A at that object. If the eye is moved in a direction perpendicular to the orientation of the light beam, it will receive other rays, but since all rays are parallel, the eye will see the point light source in the same direction, only slightly shifted from its initial position to a distance equal to that of the motion of the eye. The lens of a sight is no larger than 5 to 6 cm in diameter; for this reason, if we move our eye from one edge of the lens to the other, the source of light will move the same distance. Therefore, if we choose to provide a sight line in this manner, the position of the eye will not matter for practical purposes. A shift of the point of aim by some 5 to 6 cm is negligible compared to the dimensions of the target and may be disregarded.

When the lens is turned on its vertical or horizontal axis at an angle, the

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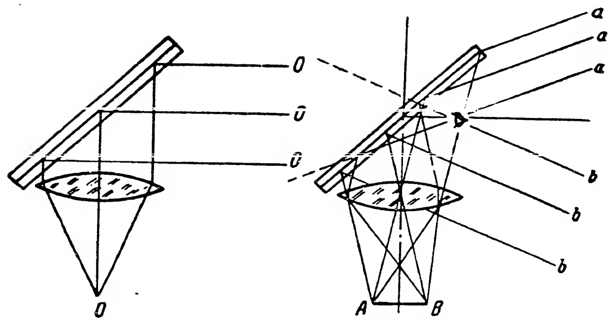

Fig. 119. A reflector directs the rays from the grid to the eye of the gunner.

entire beam of light is inclined at the same angle. Therefore, if we install the lens on a gun, we will be able, by turning it, to give any desired position to the line of sight relative to the bore axis.

Such a "sighting device" cannot be used for the following reason.

To obtain a point source of light in front of the lens in its focal plane, it is necessary to install at that point an opaque shutter with a pin-point perforation in its center. It will be this luminous point that the eye will see on the prolongation of the light beam it receives. Since the eye has to be placed rather close to the lens, it will not see anything except this luminous point, since its field of vision will be covered by the lens and the shutter. To allow the gunner to see simultaneously both the luminous point representing the sight axis, and the target, it is necessary to remove the lens and shutter from his field of vision.

To this purpose, the entire system - light source, shutter, lens - is turned around so that the optical axis of the system is vertical, and a reflector is provided so that the rays from the light source reach the eye of the gunner. The re-

flector is made of two flat pieces of glass glued together and coated on their interior surfaces with a thin layer of silver amalgam. Such a reflector lets through part of the light, while reflecting the other part. Some of the light rays from the luminous perforation, issuing from the lens in the form of a parallel beam, will pass through the reflector, while some, still in the form of a parallel beam, will strike the gunner's eye. The gunner will see the luminous point on the prolongation of the beam reaching his eye, i.e. beyond the reflector. Through this reflector, the gunner will also see the target, since only part of the light rays issuing from the target will be reflected upward, while the remainder will be reflected into the gunner's eye. In this way, the field of vision of the gunner is practically free. By varying the angle of inclination of the reflector, it will be possible to form the angle of sight, while by turning the entire system on its vertical axis, the sight axis may be inclined at the angle of deflection and actual own speed thereby taken into account.

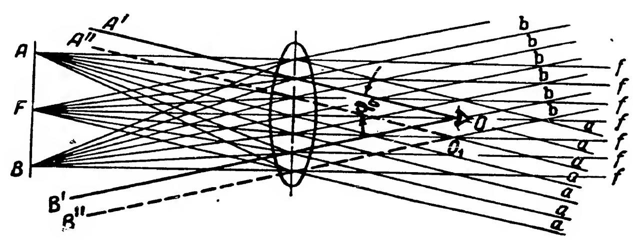

Fig. 120. Obtaining a cone of sight by means of a collimator. The rays which reach the eye from peripheral points of the grid form a cone.

Thus, by means of the collimator sight, it is possible to allow for gravity drop and own actual speed. The way in which this is accomplished in practice will be subsequently examined. Now let us see how it is possible with this system to form the cone of sight.

Let us imagine that, between the light source and the lens, is placed not a perforated shutter but a glass slide, coated with silver amalgam on the side facing the light bulb. Such a slide will not let through a single ray of light to the lens.

If we now etch out a circle on this slide, rays will reach the lens through the transparent groove thus provided. Each point on the circle will direct a divergent beam toward the lens, and this beam, upon passing through the lens, will become parallel, since the slide is situated in the focal plane. Such a beam will cross a ray originating in the center of the circle at the same angle as that formed by a ray from the circumference of the circle and aimed at the center of the lens crossing a ray, also aimed at the center of the lens, originating in the center of the circle(Fig. 120). This means that by selecting the appropriate radius for the circle on the lens, it is feasible to have these rays cross at the computed lead angle. The eye of the gunner will simultaneously see, in direction OF, the center of the circle in the form of a point of light, and, in direction OA', a given point on the circumference of the circle. Lines OF and OA' will form a specific computed lead angle ψ_o, valid for determined target velocities and foreshortenings under certain average conditions of fire.

If the eye of the gunner moves from position O to position O_1, it will receive other light rays, originating in the center of the circle and from a given point on it, but since all rays originating at a given point on the slide are parallel to one another, the angle formed by rays originating in points A and F will not vary, whatever the position of the eye. Since the eye of the gunner will receive rays from all points on the circumference, it will see a circle of light beyond the reflector. This circle will be the equivalent of the ring in iron sights. A ray from the eye of the gunner to any point of this circle will be the generatrix of the cone of sight, whereas a ray aimed at the center of the circle will be the sight axis.

The opaque slide bearing the incised circle, as well as a pipper and ranging

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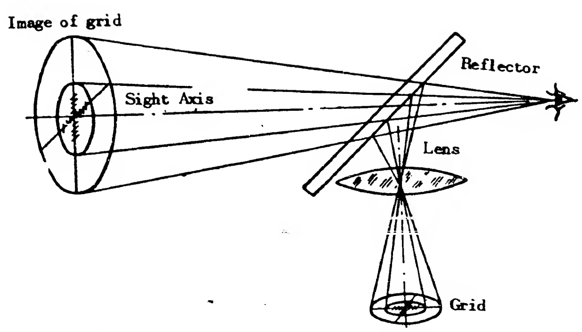

Fig. 121. Diagram of construction of cone of sight in a collimator sight.

graduation, is called a grid. The characteristic feature of the optical system described by us is that it converts a divergent light beam into a parallel one. This system is called a collimator optical system.

Thus, by means of the collimator system, we are in a position to provide a sight axis, whose position is determined by the direction toward the luminous center of the ring or pipper, and a sight cone, whose opening is determine by the apparent angular size of the image of the circle. Since a very narrow beam of light reaches the eye of the gunner from any point on the periphery of the grid, the image of each point of the ring will be situated at infinity and, therefore, the image of the ring itself will be at infinity. To the gunner it will always appear as if the image of the ring is situated at the target, i.e. in sighting, the impression is created that the target and the ring are in the same plane. This greatly facilitates setting the sight.

Let us now examine the design of the some of the simpler collimator sights

used on stationary and mobile installations.

65. Sight PAK-1

Sights designed for fire from fixed gun installations are among the simplest in design. Since the orientation of the piece in a fixed installation is the same as the direction of flight, there is no necessity to design the sighting mechanism to account for own actual speed. The actual speed of the airplane may be taken into account when setting the correction grid of the sight and boresighting the piece.

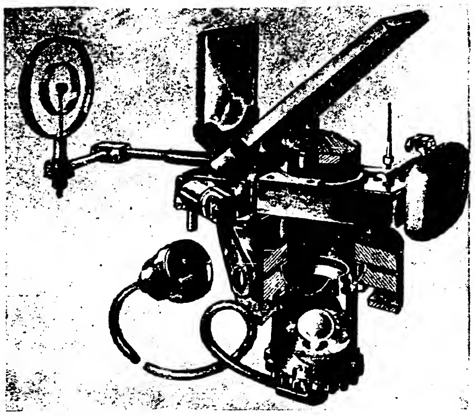

Fig. 122. Aerial gun sight PAK-1.

One of these sights, which has been used on our interceptors in fire from fixed automatic gun installations, is the sight PAK-1, whose designation signifies: "Collimator Type Aerial Sight 1".

The basic part of this sight is the optical device providing the correction grid. This part is termed the collimator sight or simply the collimator. It consists of a lens, a correction grid laid out on a concave glass slide, and a re-

flector. The grid is lighted from below by an electric bulb, which is connected to the lighting system of the airplane.

Light rays originating from the bulb, having passed through the transparent design of the grid, reach the lens, where they are refracted and, on their way out, come up against the reflector, which directs them to the eye of the gunner. Since the rays originating at any point of the grid reach the eye of the gunner in the form of a parallel beam, the gunner sees an image of all points of the grid at infinity.

The gunner, looking through the reflector as through ordinary glass, sees at the same time both the grid and all objects ahead. The reflector of the collimator has mounting so as to leave the gunner's field of vision unimpeded. Consequently, the gunner sees all objects with equal clarity whether they are seen in the reflector or outside of it. In the course of observing and aiming at the target, if the latter is situated to one side of the grid, the gunner may still watch it without interruption, and continue setting his piece when the target is seen through the reflector.

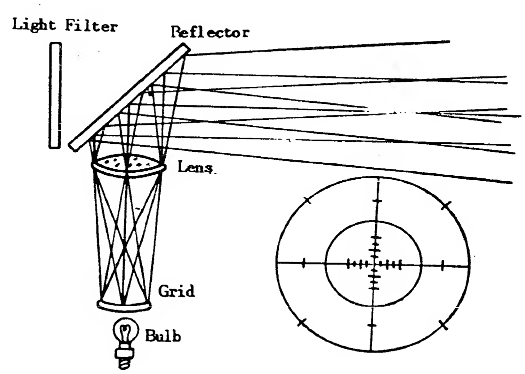

Fig. 123. Optical system and grid of sight PAK-1.

It may be said that, in fact, there are no objects in front of the gunner limiting his field of vision, there being only the virtual image of the grid which will always appear on target, whatever the range of the latter.

If sighting is on a target against a very light background of clouds or snow, the image of the grid becomes discernible with difficulty. To maintain the visibility of the grid in such cases, a filter of dark glass is placed in front of the reflector. This filter absorbs some of the light of the bright background, without barring the way to light aimed at the eye of the gunner from the lens. When not needed, the light filter may be flipped off forward by means of a special release on the left side of the sight.

The corrective grid of the sight consists of two thin lines crossing each other at a right angle: one is vertical, the other horizontal. The point at which the lines cross represents the sight axis. Two circumferences are drawn around this point. The radius of the smaller one of these corresponds to a lead angle equal to 70 mils, while the radius of the larger circle assumes a lead angle of 140 mils.

The radii of both rings are computed for fire from a piece which will impart an initial velocity $v_o = 820$ m per second to the projectile, installed on an airplane having an actual speed $V_1 = 400$ km/hr. These calculations are for an altitude of fire $H = 4000$ m.

Under these conditions, the larger ring allows for a target velocity $v_{ts} = 400$ km/hr at a foreshortening of 4/4, or $v_{ts} = 800$ km/hr at a foreshortening of 2/4. The smaller ring allows for foreshortenings of 2/4 and 1/4 for the same velocities, respectively.

The crosshairs of the grid are marked with transverse notches of alternating lengths. This is the ranging grid of the sight. Each small division of this grid corresponds to 10 mils, while each large one contains 20. The total vertical and horizontal span of the grid is 80 mils, i.e. 40 mils to the right and to the left, and upward and downward from the pipper.

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In the event of the failure of grid illumination, the sight is provided with an emergency sighting mechanism, consisting of rings fastened to a special support, and a sight post. The emergency ring-type iron sight is computed for the same target velocities and foreshortenings as the corrective grid of the sight proper. When the optical system of the sight is in operation, the emergency sight may be conveniently removed.

66. Operation of Sights in Firing on Aerial Targets, Sighting by Computation

For fire on aerial targets with sights geared to fixed and mobile gun installations, several methods of sighting may be used. These methods differ among themselves in their accuracy and in the complexity of the operations which the gunner must perform. One of the methods of sighting - fuselage ranging - has already been examined in some detail, and we need not consider it again. Let us now analyze those methods of sighting which are based on the estimation of angular lead for various target velocities.

Three methods of sighting on the basis of angular lead estimation are currently in use. They are:

1. Sighting by computation.
2. The method of comparing velocities and foreshortenings.
3. The method of arbitrary units.

Sighting by computation is based on the accurate calculation of lead angle from the formula:

$$t = 1000 \frac{v_{ts}}{v_{sr}} \sin q.$$

The calculation of lead angle by this formula can only be carried out on the ground, in advance, and requires an advance knowledge of target velocity, foreshortening, range and altitude of fire, as well as the absolute initial projectile velocity which depends, for a given piece, on angle-off and own actual speed. All these data cannot be available in advance for any combat situation. For this reason

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the method is used only in practice fire, when conditions allow the advance knowledge of all the data needed to compute the angle of lead. Such practice fire may be directed at cones, i.e. special targets towed by airplanes, in the form of sail-cloth bags in the shape of truncated cones.

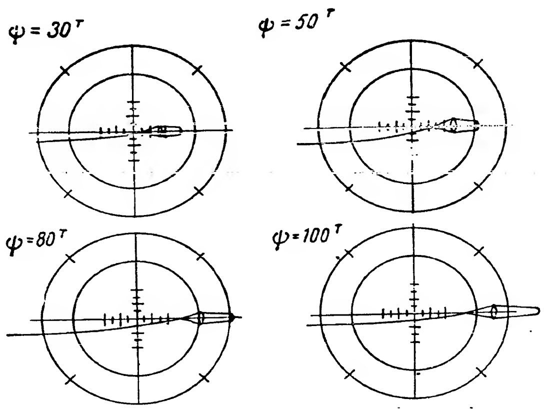

Fig. 124. Position of cone in grid of sight K8-T for varying set forward points.

To determine the position of the target in the sight grid, use is made of the radii of the rings, whose angular dimensions are known in mils, and of the ranging grid as scales. If the lead computed does not exceed 40 mils, one may simply use the ranging grid; if it exceeds 40 mils, one must use the ranging grid and the radii of the circles both.

Fig. 124 gives examples of the positions of a target cone in the grid of a sight of type K8-T for leads of 30, 50, 80 and 100 mils.

In sighting with sight K8-T, it is necessary:

a) before take-off, to register on the actual speed indicator lath the speed

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required by the exercise;

b) upon turning in on the target, to aim the piece in the direction of the target and to find the position of the point of aim on the sight grid in accordance with the target's line of motion and the computed lead angle;

c) set the piece so that the point of aim be so placed that the fore and aft axis of the target along its line of motion pass through the pipper of the sight;

d) when the target is viewed at the foreshortening allowed for, to open fire.

67. Sighting by the Method of Comparing Velocities and Foreshortenings

Less accurate than sighting by computation, yet more rapid and practical is the method of comparing velocities and foreshortenings. The sight rings or, more exactly the radii of the sight rings, are designed for definite target velocities and definite foreshortenings. Since the lead angle is directly proportional to the velocity and foreshortening of the target, while the radius of the ring is directly proportional to a particular lead angle calculated in advance, the radius of the ring must be larger to the extent that the velocity of the target and its foreshortening are greater.

If the sight ring is designed for a target velocity of v_{ts} = 400 km/hr and a foreshortening of 2/4, while the target fired at has a velocity of, say, 800 km/hr, and the same foreshortening, the point of aim when sighting should be taken not on the ring, but at a distance of two radii from the pipper of the grid, i.e. at a distance greater than the radius of the ring by as many times as the actual velocity of the target exceeds that provided for by the radius of the ring. If the velocity of the target is inferior than that allowed for by the ring, the distance of the point of aim from the pipper must be diminished by as many times as the actual velocity of the target is inferior to that provided for.

If the foreshortening of the target is greater or lesser than that provided for, the distance of the point of aim from the pipper of the grid should be in-

creased or decreased by as many times as the actual foreshortening is greater or lesser than that provided for.

Thus, under combat conditions, the gunner is expected to determine target velocity and foreshortening, and to select a point of aim on the sight grid in accordance with these data and the data built into the sight.

We have already stated previously that the gunner has no direct way of estimating target velocity, and that he has to judge it from the class of aircraft to which the target belongs. Foreshortening may be judged by eye with an accuracy up to 1/4.

The method of comparing velocities and foreshortenings is notably simplified when the radii of the sight rings are computed for typical speeds of enemy aircraft. When this is the case, the gunner has only to find out which ring to use as a reference in selecting the point of aim on a given enemy plane. The gunner has then only to allow for the foreshortening of the target.

In sight K8-T, the smaller ring of the corrective grid is set for a target velocity of $v_{ts} = 400$ km/hr and a foreshortening of 2/4, while the larger ring provides for a target velocity of $v_{ts} = 600$ km/hr and an identical foreshortening of 2/4.

Unless fire is directed on a jet plane, all targets may be divided into two classes: interceptors and bombers. It may also be assumed that all interceptors have speeds of 600 km/hr, and all bombers speeds of 400 km/hr. In sighting on interceptors, one thus may use the larger ring of the corrective grid, while using the smaller one for bombers.

When sighting from an interceptor or strafer, it is required:

a) to determine the class (interceptor or bomber) to which the enemy plane should be assigned, and to select the appropriate sight ring;

b) to determine the foreshortening of the target and to find out at what distance from the pipper the target must be located at the moment fire is opened;

c) to maneuver the plane so as to place the target in the field of the sight

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in such a way that its longitudinal axis in the direction of flight point to the pipper of the sight;

d) to move the airplane so as to move the pipper along the axis of the target so that the target be located at the required distance from the pipper;

e) maintaining the target at the point of aim and introducing, if necessary, corrections for changes in the direction of target motion or in foreshortening, to wait until the range to the target corresponds to the effective range of fire, and to open fire.

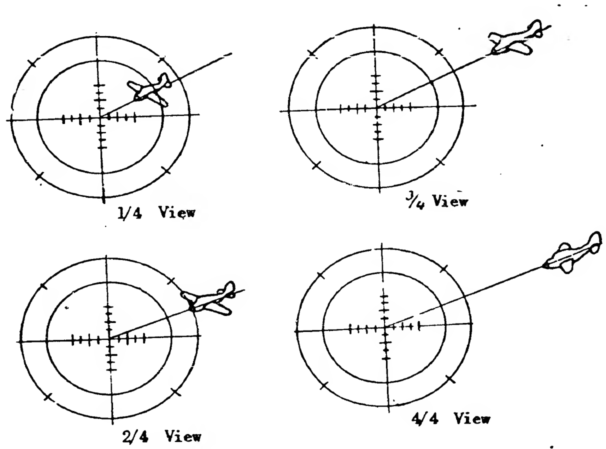

Fig. 125. Sighting on pursuit plane by the method of comparing velocities and foreshortenings.

When aiming with sights of type K8-T attached to mobile installations, it is required:

a) before take-off, to register the expected speed or the one set for the particular task on the actual speed indicator lath;

b) having located the target, to determine the class to which it should be

assigned, and to select the corresponding sight ring;

c) to estimate the foreshortening of the target and find out at what distance from the pipper of the grid the target must be situated at the moment fire is opened;

d) to set the piece in such a manner that the target be in the sight field and that its longitudinal axis point in the direction of its motion at the pipper of the grid;

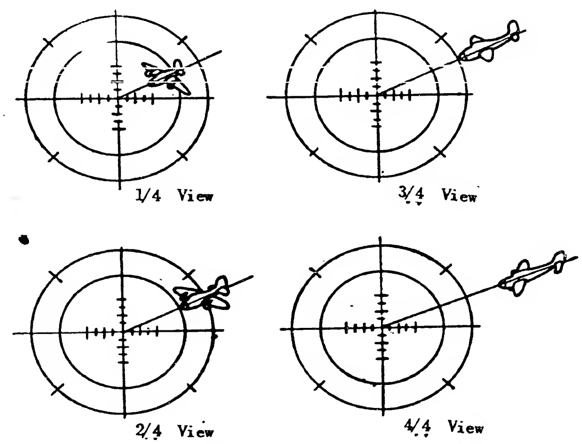

Fig. 126. Sighting on bomber by the method of comparing velocities and foreshortenings.

e) turn the gun so as to shift the pipper along the axis of the target so that the target is at the required distance from the pipper;

f) maintaining the target at the point of aim and introducing, if necessary, corrections for changes in the direction of target motion or in foreshortening, to wait until the range to the target corresponds to the effective range of fire, and to open fire.

In using this type of sight and estimating target foreshortening, it is better to overestimate than to undersetimate, and it is advisable judge of the lead angle as larger, rather than smaller than it really is.

If the lead allowed for target velocity is inferior to its correct value, not a single shell will hit the target, since the projectiles will all pass aft of the target. If we allow a somewhat greater lead than the correct value and open fire, the target will be struck if the gunner, without moving his sight, fires a sufficiently long salvo, since sooner or later the target will cross the shell trajectory.

The above described method of sighting requires no calculations on the part of the gunner, and therefore is the simplest. The gunner must be well trained to set his sight automatically as soon as he sees the target. At the same time, it is also

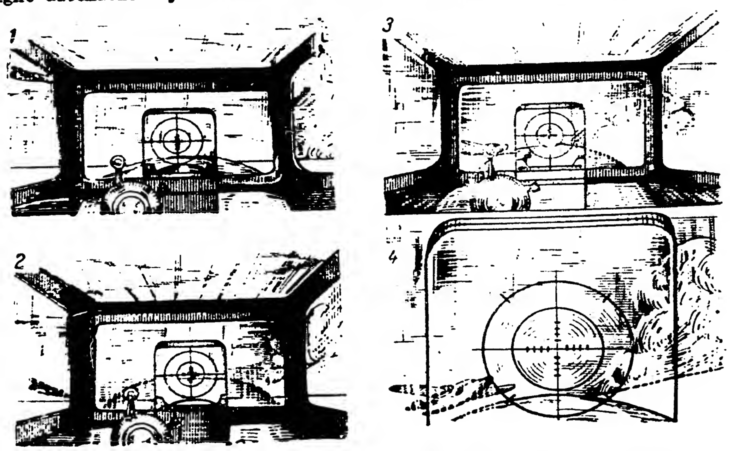

Fig. 127. Sequence of operations in sighting aerial target. 1- Having located target, recognize it; 2- Turning in on target and approaching it, calculate lead angle; 3- Orient course of own plane so that target's fore and aft axis points to pipper of sight; 4- When the target is at the calculated interval from the pipper, open fire.

the least accurate method, since target velocity may significantly differ from those

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for which the sight rings are designed. If target velocity is too low, the resulting lead will be greater than the one required, but if firing is extended in time, the target may eventually be struck. If target velocity is too high, the lead allowed for in firing will be too small, and the target will not be hit.

68. Sighting by the Method of Arbitrary Units

Another method of sighting, requiring some simple calculations, but more accurate in principle than the method of comparing velocities and foreshortenings, is termed the method of arbitrary units. This method permits taking accout both of the true speed of the target and its foreshortening.

The precise value of the lead angle is found by the formula:

$$\psi^{T} = 1000 \frac{v_{ts}}{v_{sr}} \sin q.$$

As we noted earlier, the mean velocity of the projectile in flight may be assumed constant, and calculated for a given average altitude H, a given range of fire D, and own actual speed V_1.

The foreshortening of the target, defined by the value sin q, is in terms of quarter fuselage lengths and may be written as $\frac{k}{4}$, where k is the numerator of foreshortening, which may assume the values 0, 1, 2, 3 and 4. If group all constant values in one member, the formula for lead in mils may be written as follows:

$$^{T} = \frac{1000}{4_{sr}} v_{ts} k$$

The constant member $\frac{1000}{4_{sr}}$ may be calculated in advance, and, when firing in the air, the gunner will have to multiply three figures to obtain the lead angle: the value of this constant member, target velocity and the foreshortening numerator. Considering the speeds of modern aerial combat, the calculation is somewhat cumbersome, especially since target velocity must be taken in meters per second.

To simplify the problem, target velocities are expressed in tens of kilo-

meters. To express a velocity given in kilometers per hour in meters per second, it is necessary to convert the value for velocity from one system of units to another. In this instance, to derive [m/sec] from [km/hr], the velocity in km/hr must be divided by 3.6, i.e.

$$v_{ts}[\text{m/sec}] = \frac{v_{ts}[\text{km/hr}]}{3.6}.$$

If we have velocity in tens of kilometers per hour enter in this formula, we are introducing thereby a value which is ten times smaller than the actual one, and the formula must be given the factor 10, i.e.

$$v_{ts}[\text{m/sec}] = \frac{10 v_{ts}[\text{tens km/hr}]}{3.6}.$$

The figure $\frac{10}{3.6}$ may be carried to the constant member of the formula, and we then get:

$$\psi^{T} = \frac{1000.10}{3.6 \cdot 4_{sr}} v_{ts}[\text{tens km/hr}]k.$$

For a mean projectile velocity v_{sr} equal to 700 m/sec, the value of the constant member equals approximately 1. For other values of mean projectile velocity, the value of this constant member differs somewhat from unity but, to simplify the problem, it is always taken as equal to unity. Using this approximation, the product of target velocity, expressed in tens of kilometers per hour, and of the numerator of foreshortening will represent the lead angle not in mils, but in certain other units, differing from mils. These units are termed arbitrary units.

Thus, lead angle may be obtained from the formula:

$$\psi = v_{ts}[\text{tens km/hr}]k[\text{arbitrary units}]$$

Now that we have the lead angle in arbitrary units, how do we set the sight by it? For the sight gives angles expressed in mils on the ranging grid and ring radii. The solution will be found if we can express the angular values of the ring radii also in arbitrary units. This is not hard to do, keeping in mind the fact that the radius of each ring is also calculated for a specific foreshortening and a specific target velocity. By multiplying the numerator of foreshortening by

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the velocity on which the radius of the ring is based, we will find its value in arbitrary units.

In this way, we will obtain a lead angle to scale for purposes of sighting, which will be expressed in the same units as the lead angle obtained by computation.

What then will be the angular dimensions of ring radii in arbitrary units for sight K8-T? The small ring in this sight is calculated for a target velocity of 400 km/hr and a foreshortening of 2/4. Consequently, the angular magnitude of the radius of the small ring expressed in arbitrary units will equal 40 x 2 = 80 arbitrary units. The large ring is calculated for a target velocity of 600 km/hr and a foreshortening likewise of 2/4. Therefore, the radius of the large ring in arbitrary units will equal 60 x 2 = 120 arbitrary units.

We thus find that, for sight K8-T, the number of arbitrary units contained in the ring radii is equal to the number of mils in those same radii. This means that the data built into the grid of sight K8-T are such that the constant member of the formula for the lead angle is precisely equal to unity, and the arbitrary unit therefore equals exactly one mil.

This concordance does not hold true for other sight grids. As a result, the constant member in the formula for lead angle comes out somewhat smaller than 1, and the arbitrary unit is somewhat smaller than one mil. In such sights, the smaller ring of the grid measures 70 mils or 80 arbitrary units, while the larger one measures 105 mils or 120 arbitrary units. When using the method of arbitrary units, the smaller ring should therefore be taken as measuring 80 arbitrary units, and the larger ring, 120 arbitrary units. However, considering the very small difference between the number of mils and the number of arbitrary units contained in the radii of the rings, it may be assumed that these contain the same number of arbitrary units as of mils, i.e. 70 and 105 arbitrary units. In addition, leads of 80 and 120 arbitrary units will be taken not on the rings, but respectively at 10 and 15 mils outside of them. In other words, leads deliberately greater than

those required by computation will be taken. We have already noted that such a procedure is more advantageous than underestimation of lead.

In sighting by the method of arbitrary units, it is required:

a) having located and recognized the target, to determine its velocity by reference to the class of aircraft to which it belongs;

b) if the target is already at relatively short range, to determine its foreshortening; if it is at long range, to select the foreshortening at which it will be attacked;

c) to multiply target velocity in tens of kilometers per hour or, simply, in km/hr without the final figure, by the numerator of its foreshortening, and to find out the distance from the pipper at which the target must be situated at the moment fire is opened;

d) to maneuver the plane to place the target in the sight field, so that the target's longitudinal axis points to the sight pipper in the direction of its motion;

e) move the plane so as to shift the pipper along the axis of the target in such a way that the target be situated at the calculated distance from the pipper;

f) maintaining the target at the point of aim and introducing, if necessary, corrections for changes in the direction of motion or foreshortening of the target, to await the moment when the range of the target will correspond to the effective range of fire or the moment when tactical conditions are those required for attack, and open fire.

In sighting from mobile installations equipped with K8-T sights, and using this method of sighting, it is required:

a) before take-off, to register the expected speed or the one set for the execution of the particular task on the actual speed indicator lath;

b) having located and recognized the target, to determine its velocity by the class of aircraft to which it belongs;

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c) to determine the foreshortening of the target and by multiplying the numerator of foreshortening by target velocity expressed in tens of kilometers per hour, find the lead angle in mils;

d) to set the piece in such a manner that the target be in the sight field and that its longitudinal axis point in the direction of its motion at the pipper of the sight grid;

e) to turn the gun so as to shift the pipper along the axis of the target to place the target at the required distance from the pipper;

f) maintaining the target at the point of aim and introducing, if necessary, corrections for changes in the direction of motion or foreshortening of the target, await the moment when the range to the target corresponds to the effective range of fire or when the target is seen at its most advantageous angle, and to open fire.

The reader may now ask: "Which of the three methods described should be employed in aerial fire?" We will answer this question in greater detail when we examine firing techniques for ground and air targets. In the meantime, we will

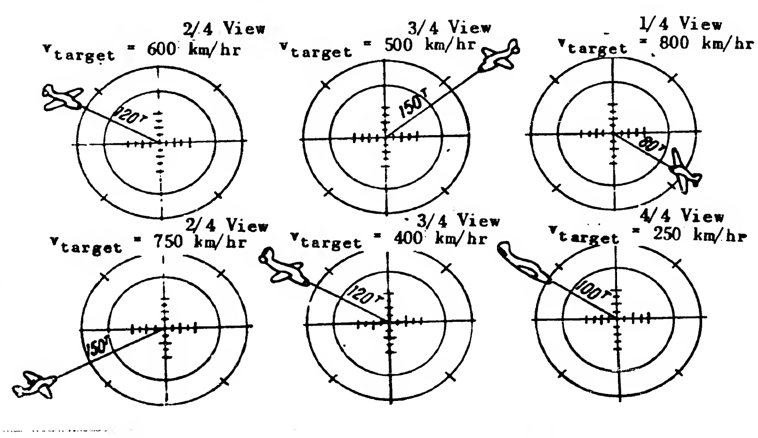

Fig. 128. Sighting by the method of arbitrary units.

merely state that all three methods may be used with equal effectiveness, depending on the firigg technique adopted. Particular sighting methods suit particular firing techniques better than others.

69. Using Sights when Firing upon Ground Targets

Aerial machine-guns and guns may be used in fire on ground targets. Typical ground targets include grounded aircraft on airfields, trucks, armored cars, light and medium tanks, horse and railroad transport carrying personnel or equipment, infantry and artillery in position and in transit. Ground targets are divided into pin-point targets (occupying a negligible surface), long narrow targets, and wide-area targets. Pin-point targets include small groups of personnel, lone grounded aircraft, individual trucks and cars, tanks, armored cars, artillery pieces, machine-gun nests, etc. Long narrow targets include infantry, transport and armored columns, trains, etc. Wide-area targets include sectors of the ground or inhabited points occupied by enemy troops, troop concentrations at river crossings, airfields, artillery installations, etc.

When firing upon small ground targets, the gunner is required to aim accurately. Sighting at such targets involves setting the sight axis or grid pipper at the point of aim. If the target is stationary and there is no wind, the pipper of the sight grid should coincide with the center of the target. When there is wind, the grid pipper is shifted to a point carried windward to the distance of linear wind deflection or, if the angle of wind deflection is known, in accordance with this angle. Under combat conditions, a linear correction for wind is usually used. This linear correction, when determined, is measured out by eye using the dimensions of the target as units of scale.

As we already know, the linear correction for wind deflection equals the product of wind velocity by projectile flight time. The latter depends on the range of fire and the actual own speed of the plane, and cannot be calculated accurately

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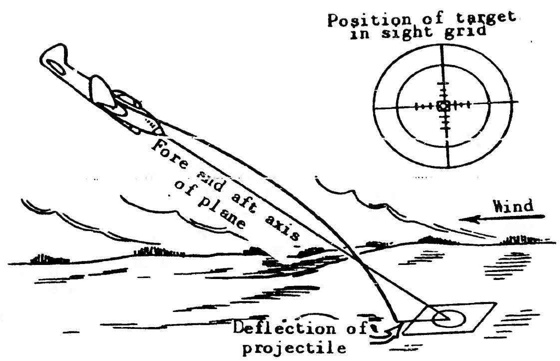

Fig. 129. Sighting on a pin-point ground target in this manner is permissible only in the absence of wind (if there is wind, the projectile will be deflected from the target.

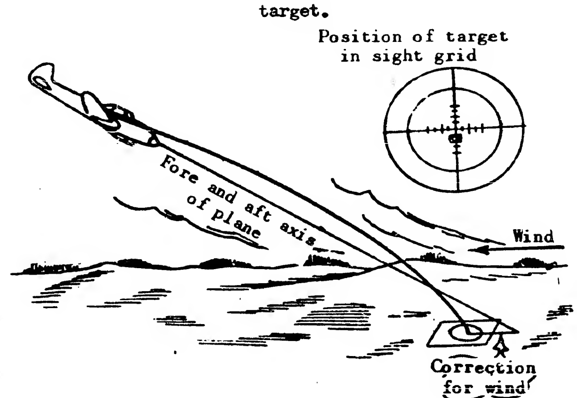

Fig. 130. This shows how to make a correction for oncoming wind when sighting on a pin-point ground target.

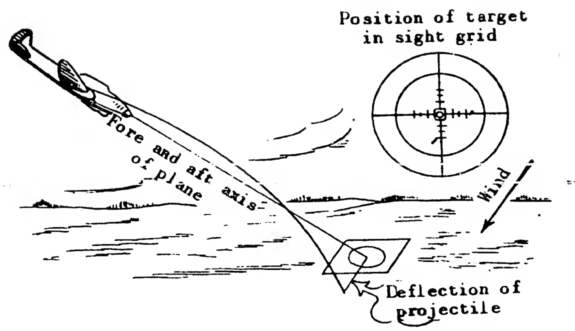

Fig. 131. This shows the deflection of the projectile as a result of side wind, if center of target is aimed at.

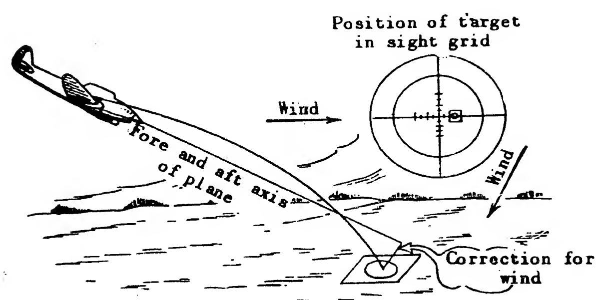

Fig. 132. This shows correction for side wind.

by the gunner. For this reason, it has to be determined approximately from range of fire. The time of flight of the projectile for ranges of 600 to 900 m is taken as equal to 1 second, and, for ranges below 600 m, to 0.5 seconds. Consequently, for ranges of 600 to 900 m, linear correction for wind is numerically the same as wind velocity, while, for ranges of less than 600 m, it corresponds to one half of wind velocity.

Wind direction and velocity are determined from the drift of the airplane and from smoke and dust drift at ground level. If, for one reason or another, it is impossible to gauge wind direction and velocity, fire is opened without allowance for wind, and corrections are subsequently introduced by observing the explosions of the shells and the dust raised by them on the ground. In cases when wind velocity does not exceed 5 meters per second, or range is less than 300 to 400 m, no allowance is made for wind.

In fire on moving ground targets, corrections are introduced for the velocities of these targets. In these cases as well, linear correction is generally taken. To allow for target velocity, the point of aim is carried forward in the

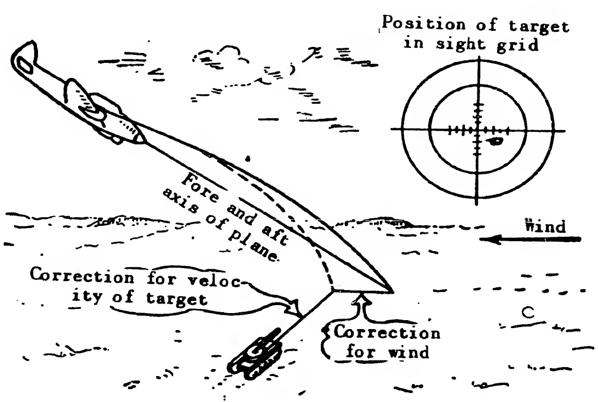

Fig. 133. Sighting on a moving ground target when there is wind.

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direction of target motion to the distance of linear lead, gauging this distance by eye in terms of target size. The linear correction for target velocity equals target velocity by projectile flight time. The latter, as in wind correction, is taken in round figures, i.e. for ranges of 600 to 900 m, the correction for target velocity equals target velocity, while at lesser ranges it is half the value for the same.

In order to take into account both target velocity and wind in air to ground fire, it is necessary to carry the point of aim forward along the line of motion of the target to a distance equal to linear lead, and from this point to one side, in a direction contrary to that of the wind, to a distance corresponding to correction for wind deflection. In fire on long narrow targets, wind is allowed for only when it is directed transversely in relation to the target. In fire on wide-area targets, such as troop concentrations, airfields, population centers, etc., correction for wind is not made. At the same time, it is still required to aim at specifically selected, more important and vulnerable parts of the target.

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Chapter XII

FIRING ON AIR AND GROUND TARGETS

70. Why and How Range to Target Is Determined

The range of fire from an airplane machine gun or cannon is considered close if it does not exceed 200 m, medium when it varies from 200 to 600 m, and long when it exceeds 600 m.

Fire directed by means of ring sights is most effective at close ranges. Fire at medium ranges is mainly employed when attacking aerial targets on approaching courses and when repelling interceptor attack from a bomber. Fire at long range is ineffective and is permissible only when attacking aerial targets on approaching courses, or when a high calibre piece is used on a relatively slow-moving target.

In fire on pin-point ground targets, effective range is limited to 600 m.

To have some assurance of striking the target by fire from a machine gun or automatic cannon, both the gunner and the pilot must be careful to open fire only at those ranges at which fire is most effective. Therefore, the gunner and the pilot must know how to determine the range to the target rapidly and with sufficient accuracy.

There are two ways to determine range: by eye, and by means of the sight.

Ranging by eye depends on the ability of the eye to see objects at various distances in varying fullness and detail. Thus, at ranges of 800 to 1000 m, only the main parts of a plane are visible: wings, fuselage, and tail assembly. At ranges of 400 to 500 m distinct parts of the wings, fuselage and empennage are visible, as well as the juncture of the cockpit and the fuselage and the stabilizer. At a range of 200 m, smaller details are visible: the cockpit frame, exhaust pipes, etc. At a range of 100 m, the most minor details may be distinguished: slits in the empennage, gun openings in the fuselage and wings, the antenna, etc.

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To learn to range the target by eye, the gunner must train systematically and learn through practice. Personal experience and training must help him to find for himself the degrees of visibility of various features of airplanes for varying ranges, and make up a table of criteria. It is impossible to set up tables which would be of use to all gunners, since the degree of visibility of particular airplane features depends on the individual eyesight of every gunner.

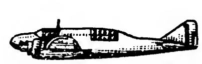
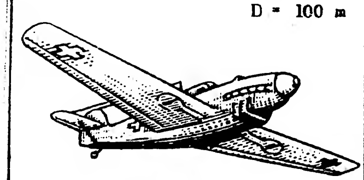
D = 800-1000 m 	The main parts of the plane, e.g. the wings, fuselage and tail assembly, are clearly visible
D = 400-500 m 	Parts of wings, fuselage, tail assembly, the juncture of the cockpit with the fuselage and the stabilizer are clearly visible
D = 200 m 	Smaller details are visible, e.g. the cockpit frame, the exhaust pipes, the antenna, etc.
D = 100 m 	The most minor details are visible, e.g. slits in the empennage, gun openings in the fuselage and wings, the antenna, etc.

Fig. 134. Determining range by eye.

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This method, which is the simplest and most rapid, allows range determination with an accuracy adequate for practical purposes.

Range determination by means of the sight is based on the measurement of the angular size of the target in mils.

The angle in mils at which a target of size 1 is seen is defined by the formula $\varphi^T = 1000 \frac{1}{D}$, where D is the range to the target. Obviously, if we know the size of the target and if we can determine the angle at which this size is perceived, we may determine target range by modiying our formula to read:

$$D = 1000 \frac{1}{T} .$$

Since in aerial combat the target is usually attacked at foreshortenings of 0/4, 1/4 or at the most 2/4, the most convenient method of ranging is to gauge distance from wing span. To simplify calculations apparent wing span is assumed not to vary

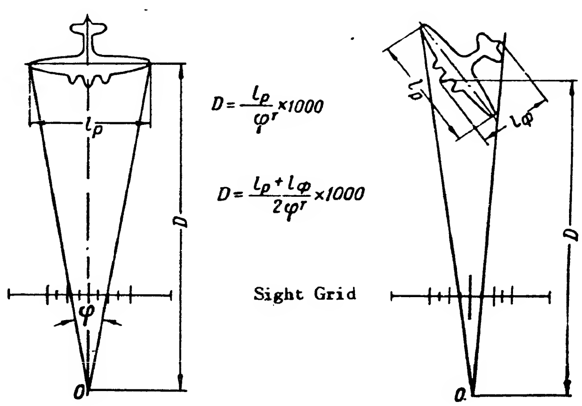

Fig. 135. Principle of range determination by means of gun sight.

with these foreshortenings, and to equal 10 m in all one-engine interceptors, 20 m in two-engine interceptors and bombers, and 30 m in three- and four-motor bombers.

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and transports.

Collimator sights have ranging scales in their fields of vision: the smaller graduations indicate 10 mils each, the larger ones – 20 mils. It is therefore easier to gauge angular dimensions not in mils, but in terms of the smaller ranging graduations of the sight. If we substitute an angle in ranging units for one in mils, we must multiply the number of ranging units by 10 to have mils appear in the formula. Representing the number of ranging graduations spanned by the target as n_1, we get:

$$D = 1000 \frac{l}{10n} \quad \text{or} \quad D = 100 \frac{l}{n}.$$

The right half of the formula may be divided by 100, and the division of l by n will give us range in hundreds of meters:

$$D = \frac{l}{n} \text{ [hundreds of meters]}.$$

In determining the number of ranging graduations occupied by the target, it is quite unnecessary to superimpose the ranging scale on the target. The gunner must be able to range by means of the sight through comparison of apparent target size with the ranging scale, whatever the position of the target in the sight grid.

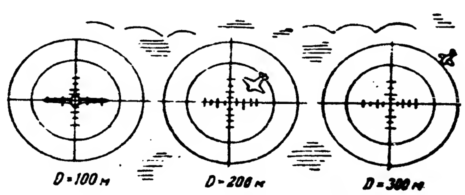

Fig. 136. Pursuit plane in sight grid at ranges of 100, 200 and 300 m.

This method of determining range to target is more accurate, but also more complicated and cumbersome in its application. Ranging by eye is therefore more

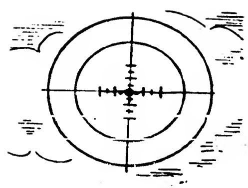

Fig. 137. Twin-engine bomber in sight grid at range of 500 m.

commonly used.

71. Rate of Fire on Air and Ground Targets

An airplane carries a relatively limited supply of ammunition, and the rate of fire of modern machine guns and cannons is such that the entire reserve may be exhausted in 10 to 20 seconds of uninterrupted fire. If the gunner uses unduly long salvos, he may find himself out of shells before aerial combat is over. Consequently, the gunner must be economical in his expenditure of shells, avoiding unduly long salvos and aiming carefully.

Experience shows that a salvo of 0.5 seconds allows the aerial gunner to increase the accuracy of the setting of his piece on the basis of shell traces, and to shift fire onto the target without interrupting fire, if original aiming was sufficiently accurate. For an accurate correction of fire on the basis of traces and continued fire sufficient to knock out the target, a salvo up to 1 second in length is required.

Fire in salvos of greater length is permissible only in such cases when the enemy remains well within the field of vision of the sight and when one is assured

that continued fire will lead to knocking out the target. However, salvos of more than 2 seconds are not permissible, as they lead not only to the rapid expenditure of ammunition, but also to the overheating of the gun barrels, causing the weapons to go out of commission.

It is generally agreed to consider salvos of up to 0.5 seconds in length as short, up to 1 second as medium, and up to 2 seconds as long.

On any combat flight, ammunition expenditure should be so calculated as to leave 15 to 20 percent of shells in reserve to the end of the flight in case of action on the return flight to home base.

72. How to Use Tracers in Correcting Fire

The ammunition belts of airplane machine guns and cannons are made to contain

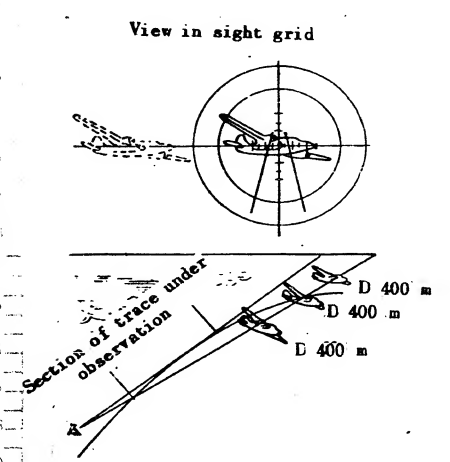

Fig. 138. When firing at ranges exceeding 400 m, it appears as if trajectories overshoot target, while they actually go under

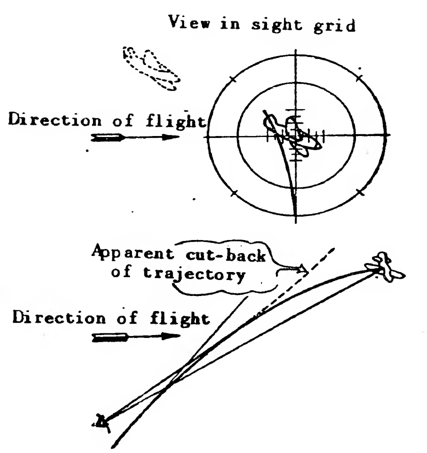

Fig. 139. When firing from mobile installations, trace appears to cut back toward the tail of the plane.

a definite percentage of tracer shells or bullets, equally distributed throughout the belt.

Traces allow the gunner to determine the position of the trajectory relative to the target and to make the needed corrections in his aim. Knowledge is needed, however, to interpret the traces, since they may appear to give misleading indications regarding the motion of the projectile relative to the target. Thus, for example, in fire at ranges of 400 m and further, the curvature of the trajectory and its rise above the line of aim create the impression that the shells are flying over the target, while in actuality the gunner is merely seeing the upper part of the trace and judging from it the direction of motion of the shells or bullets, without noticing that the trajectory subsequently lowers off. In firing from mobile

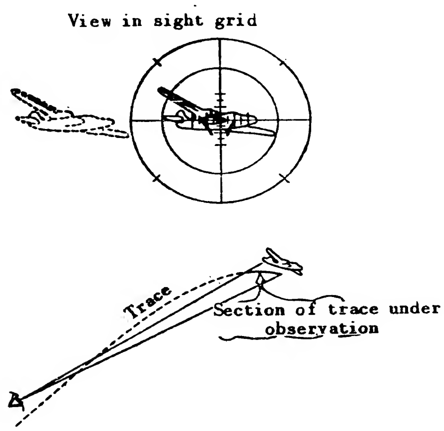

Fig. 140. The projectiles undershoot the target.

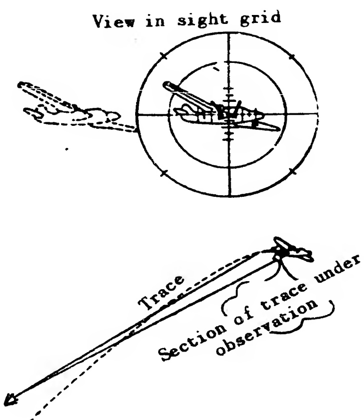

Fig. 141. The projectiles reach the target.

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pieces, the trajectory appears to cut back toward the tail of the plane. In view of all this, in firing with tracers, it is recommended to watch not the entire trace, but merely that limited portion of it that lies near the target, i.e. to look not at the trace but at the target when firing, and to make no corrections before the first bullets or shells reach the target. Whether the projectile has reached the target may be judged from the interruption of the trace or the explosion of shells at the target.

To make effective corrections from the trace, the aiming before fire must be careful, and then corrected subsequently by the deviation from the target as shown by the trace. If the deviation of the trace from the target does not exceed 5 to 10 m, the trace should be led on to the target without interrupting fire. If a larger error was introduced in the original sighting, fire should be interrupted, sighting repeated with greater accuracy, and firing then resumed.

Fire upon aerial targets with no other sighting aid than tracer indications involves large errors and consequently large expenditure of time and ammunition.

If the attacking airplane has managed to turn in on the target without being observed and the pilot or gunner has succeeded in sighting without drawing the enemy's attention, the enemy will become aware of being attacked from the traces of the first shorts fired. It is therefore imperative that the original sighting be performed with the utmost accuracy, so as to knock out the target with the first salvo.

73. How to Fire upon Aerial Targets

To be the first to attack is to be victorious. In aerial combat, the aim must be to attack the enemy first, and to knock him out with the first volley. Surprise in attack is acheived by approaching the target unnoticed. It may be done by approaching from the side of the sun, from behind clouds or on the side of the enemy's blind angle. In approaching the enemy from below, ground relief

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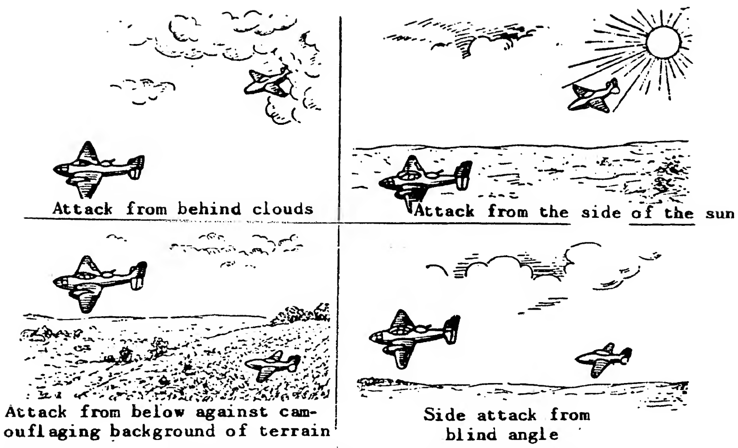

Fig. 142. Surprise attack is achieved by concealing approach to target.

is used as a camouflaging background.

Fire should be opened at the shortest range possible, yet the pilot must have sufficient time to keep up fire. For this reason, it is most advantageous to attack aerial targets from the rear hemisphere. Speed in relation to target motion must be kept down to the minimum. The target should consequently be attacked at the smallest possible foreshortening.

If it has not been possible to begin the attack unnoticed, the relative speed of the attacker plane shall likewise appear small to the enemy, and the latter will also find it easier to sight and fire at the attacker. In selecting the direction from which to attack, the pilot must take into account the distribution and effective angles of the enemy plane's guns, the enemy's armor and his vulnerable points.

The most effective conditions under which one interceptor may attack another

are considered to involve an attack from above and from the side at a foreshortening not exceeding 2/4, or on a curve under the enemy plane, with a turn-in from the rear and below. Fire should be opened at ranges not exceeding 200 m, and is first in the form of short bursts to improve accuracy from traces, then one extended salvo to knock out the target. Fire should be sustained until the shortest range compatible with a safe break-away is reached.

In attacks upon interceptors on approaching courses fire should be opened at ranges of 800 to 1000 m.

When an interceptor attacks a bomber, the first approach is usually made from the front and the side, while subsequent ones are from the rear and side or the rear and below. In frontal attacks, fire is opened at a range of 600 to 800 m, while in a rear approach the range should not exceed 200 m. The first attack should aim at the gunner of the mobile installation or the installation itself, while later attacks at close ranges of the order of 100 to 50 m should involve fire on the pilot's cabin or one of the engines.

Gunners of mobile installations are confined, in aerial combat, to defensive fire against attacking pursuit planes, and, in addition, may fire only when the enemy has entered the boundaries of the sight cone of the piece. The gunner must attempt to discover and fire upon the enemy before the enemy fires on him.

If the enemy appears in the blind angle of a mobile installation on the attacked airplane, the pilot of this plane must execute a maneuver, i.e. a turn of 10 to 15 degrees, to take the enemy out of the blind angle and allow the gunner to fire on the enemy plane. In all cases of defense against interceptor attack, whether the latter occur in the fore or aft hemispheres, fire should be opened at a range of the order of 600 m and sustained in the form of short bursts, so as not to allow the enemy to pursue his approach unhindered, and then continued by means of medium and long salvos as the target comes closer. In all cases, aim should initially be taken by means of the sight, and made more accurate from traces.

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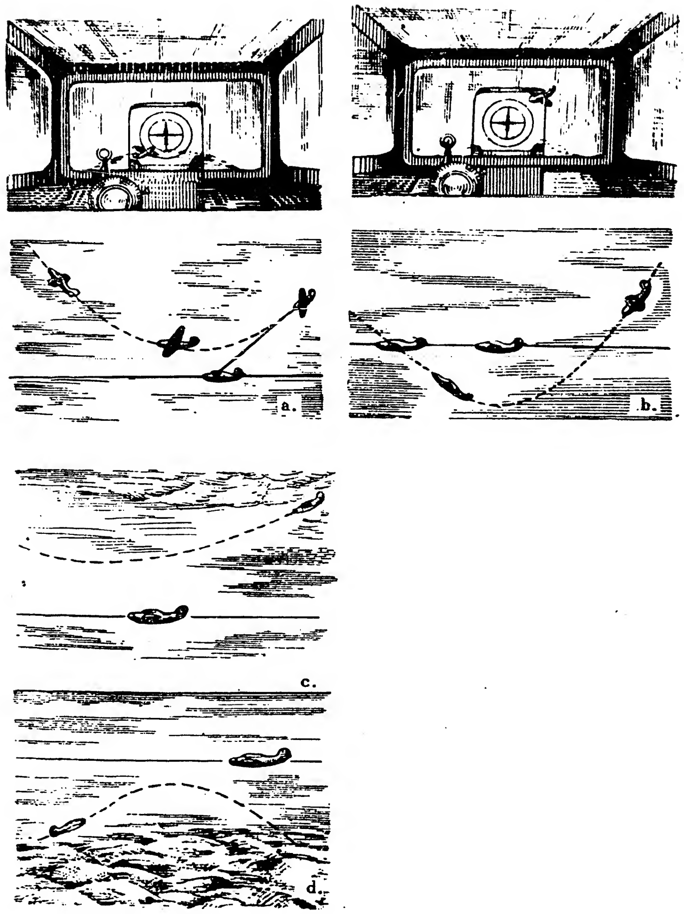

Fig. 143. Attack of fighter by fighter. a- attack from the tail, overhead, and the side; b- attack from overhead, with curve under enemy plane; c- attack from the tail, overhead; d- attack from front and below.

Two types of fire are used in aerial combat: tracking fire and barrage fire.

Tracking fire is fire in which the target is maintained within the sight grid at the required set forward position for the duration of fire, i.e. the piece is moved continuously to follow the target. The essential features of tracking fire are easy to grasp if one imagines the set forward point as being rigidly connected with the target as by a shaft, and moves with it, while the gunner, sustaining fire without interruption, keeps the pipper of his sight fixed all the time on that point. Tracking fire is used in cases when the angular velocity of target motion is insignificant, i.e. when target foreshortening does not exceed 2/4.

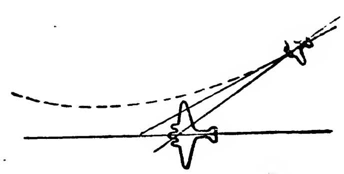

Fig. 144. Attack of bomber by fighter from the tail and side.

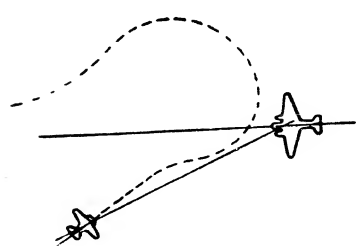

Fig. 145. Attack of bomber by fighter from the front and side.

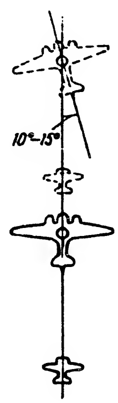

Fig. 146. Maneuver of bomber if target is in blind angle.

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Barrage fire is fire in which the gunner, deliberately allowing a lead in excess of the one required, fires without shifting his sight and, therefore, his piece,

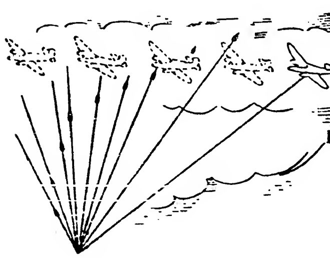

Fig. 147. Tracking fire.

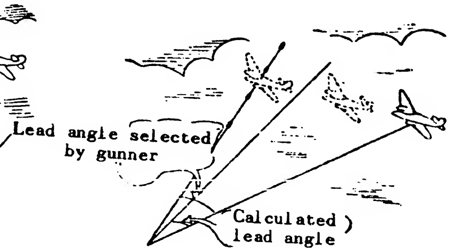

Fig. 148. Barrage fire.

awaits the moment when the target enters the sight grid with a lead smaller than the one taken.

To understand the nature of barrage fire, it must be imagined that the set forward point has a fixed position in space on the prolongation of the fore and aft axis of the target at a distance one and a half to twice the required linear lead for its velocity, and that the gunner, having placed the pipper of his sight on this fixed point, fires continuously until the true set forward point, rigidly joined to the target, passes the selected fixed set forward point. After this happens, a new set forward point must be selected on the path of the target, made to coincide with the pipper, and fired at again. It is clear that by this technique of firing all the projectiles released before the target reaches the required distance from the selected set forward point will miss the target and pass in front of it, while all the projectiles released at the moment the target is situated at the required distance from the selected point will hit the target. Fire after the distance from the target to the selected fixed set forward point is less than that required is senseless, since the target will have passed this point while the projectiles are

in flight, and the latter will therefore pass behind the target.

Barrage fire is used when the angular velocities of target motion are high, i.e. at foreshortenings exceeding 2/4.

A greater expenditure of ammunition and time is required to knock out a target by means of barrage fire.

We are now in a position to answer the question regarding the advantages of various sighting methods.

It is not difficult to see that it would be quite senseless to use accurate sighting methods in barrage fire, since the computed lead has in any event to be magnified one and a half to two times.

For this reason, the method of comparing velocities and foreshortenings is entirely adequate for purposes of barrage fire. Furthermore, no great harm will ensue if target velocity differs significantly from the velocities for which the sight rings were designed.

On the contrary, if the gunner is planning to use tracking fire on the target, he must allow for lead for target velocity with the utmost accuracy, and therefore use the most accurate sighting method, since tracking fire involves the passage of all projectiles through a point which remains at a constant distance in front of the target , which must equal precisely the required linear lead. Therefore, if the gunner has inaccurately calculated lead, and made it smaller or larger than the one required, the projectiles will pass either in front or in back of the target for the entire duration of fire. This can only happen, of course, if no tracers are released at the target. If they are, the gunner may introduce the needed corrections on the basis of their traces.

For tracking fire, the best method of sighting is that of arbitrary units, since the gunner can hardly sight by computation.

In practice fire on target cones, whether tracking or barrage, exact computation may be employed. In barrage fire, the lead obtained through computation

must be doubled. It is better, however, if training consists of the use of the same methods as will be employed later in aerial combat.

In fire from fixed pieces, sighting is accomplished by the motion of the plane itself, and the pilot is required not only to sight correctly, but also to guide the plane correctly while sighting and firing. To prevent the deflection of the projectiles, the pilot must act in time to prevent slipping after the roll-through on the target, and select his angle of bank properly. While setting his sight, he must avoid any jerky movements of the stick or pedals that might lead to wobbling or shifting of the point of aim.

After an attack on an aerial target, the pilot must maneuver either for a second attack or for break away. The maneuver must be executed with the object of attaining maximum angular velocity relative to the enemy plane, while reducing to a minimum the surface exposed to enemy fire. Within the effective area of the enemy's pieces, the pilot must avoid rectilinear flight, and break away, to the extent that he finds it possible, in the direction of the enemy's blind angles, maneuvering both in altitude and direction and slipping.

74. How to Fire on Ground Targets

Attacks on ground targets are usually performed by strafing aircraft and interceptors, firing from forward fixed machine gun and cannon installations.

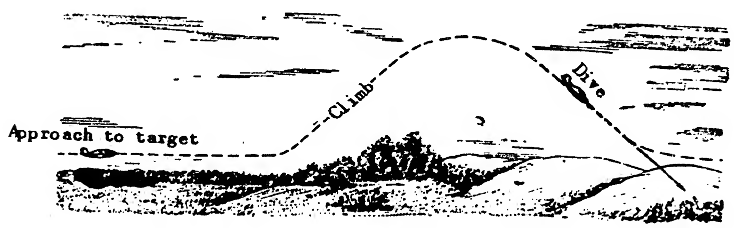

Fig. 149. Surprise attack on a ground target is acheived by concealing approach to it.

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Ground targets are very rarely fired upon from mobile installations. The success of an attack on a ground target depends primarily on the suddenness of this attack. Suddenness, as in attacks upon aerial targets, is acheived by a concealed approach to the target from the side of the sun, from behind clouds, or by contour flying, using ground relief and background as protection. The direction of attack, angle of dive and ranges at which fire is opened and stopped depend on the nature of the target under attack and are decided upon the basis of combat experience.

Attacks on pin-point ground targets, unprotected or poorly protected armored vehicles are carried out from altitudes of 600 to 800 m at angles of dive of 15 to 30 degrees. If the pilot opens fire at an altitude of 300 m, i.e. at a range of the order of 600 m, and ceases fire at an altitude of 100 to 200 m, i.e. at a range of 200 to 400 m, he has 2 to 3 seconds for firing. Beginning the attack from a range of 1200 to 1600 m ensures sufficient time for aiming (an interval also of the order 2 to 3 seconds), since at angles of dive not exceeding 30 degrees, the speed of the plane increases at a relatively slow rate. This is the technique used in firing upon small groups of personnel, isolated planes on the ground, isolated vehicles, firing installations, etc.

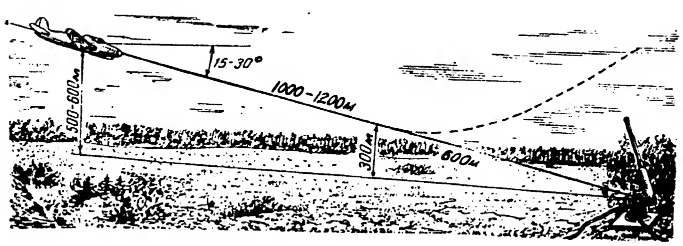

Fig. 150. Attack on pin-point ground target.

If anti-aircraft defenses exist in the area of the targets to be attacked, the attackers may suffer heavy losses from enemy anti-aircraft fire, unless special

evasive action is employed, since dives at small angles involve only slow changes in speed and altitude and the sighting of anti-aircraft guns and machine guns is thereby facilitated. Evasive action consists in the pilot changing his altitude, direction and speed of flight when approaching the target. If the pilot notices explosions of anti-aircraft shells to one side of his plane, he may use one of the more common maneuvers in this case, consisting of turning in on the burst clouds, since the anti-aircraft gunners, upon noting that their shells explode to one side of the target, will introduce corrections in their firing and set their sights over in the direction of the target. As, by then, the target will have moved, the shells will explode on the other side of the plane. This maneuver is easy to see through, and the enemy on the ground may actually fire a second salvo without correcting his aim, in which case the airplane will find itself in the zone of fire.

Many pilots use a maneuver consisting of alternating turns towards and away from the anti-aircraft explosions, such as, for example, twice towards and the third away, or some such combination. This confuses the anti-aircraft gunners and prevents them from predicting which side the plane will turn to as they prepare to fire their next round. In evasive action, variety is extremely important. Course and altitude should be varied. The combination of all these techniques allow turning in on and attacking the target. The danger of being knocked out by the anti-aircraft defenses of the enemy is at its highest at the very moment of attack, when the plane must fly in a straight line. If the angle of dive is small, i.e. if the speed and altitude of the plane vary slowly, the danger is increased. To keep down losses from enemy anti-aircraft fire, attacks on ground targets may be made from altitudes of 1000 to 1500 m at angles of 50 to 70 degrees. Fire on a plane diving at as great an angle is made difficult because both the speed and altitude of the plane are changing very rapidly. In the circumstances, however, the sighting and firing from the plane are also made difficult, since the pilot disposes of very little time for carrying out his combat assignment. Furthermore,

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apart from the fact that the speed of the airplane increases very rapidly and then decreases sharply, the pilot has to take the plane out of the dive at a higher altitude, as loss of altitude upon coming out of a dive is greater when the angle of dive is greater.

On the basis of these considerations, attacks from low altitudes are recommended. In these, the attacker airplane approaches the target by contour flying, concealing himself against the background of the terrain, then jumps to an altitude of 200 to 300 m at a distance of 3 to 4 km from the target, and attacks the latter at a small angle of dive from that altitude.

~~When attacking a pin-point armored target, fire should be opened at the closest~~ possible range and at whatever angle will cause the shells hitting the target to penetrate its armor.

Vehicle columns should be attacked from the rear or the side. Each vehicle should be aimed upon separately. The head and rear of the column should be attacked first, so as to arrest the movement of the column and prevent individual vehicles from turning back. After the end vehicles have been put out of commission, attacks should aim at destroying the column. Since vehicles are generally spaced at relatively wide intervals, continuous fire along the entire length of the column is not advised. Uninterrupted fire along the length of the column is permissible when convoys are involved, since transport vehicles are likely to follow one another at close intervals.

Tank columns should be attacked in the same manner as separate tanks, e.g. from the back or from the side. Sighting and firing should be directed at individual tanks.

Infantry columns should be attacked from low altitudes at small angles of dive. At such angles, the area under fire is increased considerably as a result of bullets and shells ricocheting from the ground.

In attacking railway transport, the locomotive must first be put out of com-

mission; then the halted train may be destroyed by repeated approaches.

Fire on large ground targets should be opened at a range of 600 to 800 m, and directed at the more important and vulnerable portions.

To time his dive and give it the correct angle, the pilot must be able to accurately determine the moment at which he is required to begin his dive. This determination is made difficult by the fact that, when the plane is in level flight, the target is hidden under the nose of the plane and cannot be seen by the pilot. To begin the attack in time, the pilot must either select a clearly visible landmark to one side, situated at approximately the same distance as the target, and, when this landmark moves into a certain position relative to the leading edge of the wing, begin his dive, or else, approaching the target so that it lies to one side of the plane, begin his attack with a turn-in on the target. In sighting at and firing on ground targets, the pilot must, as in fire upon aerial targets, guide his plane smoothly, avoiding jerky movements of the controls and wobbling.

Break-away must be performed with equal skill, since at that moment the plane is most vulnerable to anti-aircraft fire, since its lower surface, i.e., its most extensive one, is exposed.

Break-away is best performed by means of a sharp climb and a slight turn, or by contour flying with change of direction, and a subsequent climb outside of the range of enemy anti-aircraft fire.

If the target is attacked repeatedly, the maneuver should be varied, since otherwise the enemy may succeed in setting his fire and knock out the attacker plane. If upon one occasion the plane breaks away with a turn to the left and a climb, the next time it should turn to the right, and the third time leave the target at low altitude.

War history provides examples of a pilot repeatedly turning off the target in the same direction and thereby allowing the enemy to set his guns and shoot down the attacker.

In firing upon aerial and ground targets, it is most important to develop strongly ingrained responses in sighting and firing, which may be acquired only as a result of serious and systematic training.

Chapter XIII

DISPERSION OF FIRE

75. Dispersion and Its Causes

Up to now all our discussions of sighting and firing have been based on the assumption that, if the piece is properly boresighted, and if the pilot or gunner sights accurately, the trajectory of the projectile must pass through the target, and that, if the first shell in a salvo reaches the target, accurate sighting will likewise cause the other projectiles to hit the target. In actuality, this is not so. Even if, when firing on the ground, we set the piece in a fixed position and fire separate shots at a flat target, we will find that the target will have as many perforations as there were shots instead of a single perforation, as we might have been lead to expect. This means that projectile trajectories do not coincide but form what is called a sheaf of trajectories, which cluster around a specific imaginary mean trajectory. The perforations in the target also cluster around a specific central point, termed the mean point of hits, or center of dispersion. This central point may be considered as the perforation caused by a projectile following the mean trajectory.

The phenomenon of the scatter of hits on the target or the deviation of trajectories from the mean is called dispersion. If fire is from a rigidly set piece, the causes of dispersion are inequalities in the gunpowder charges of the shells, unevenness in the weights of the shells, changes in atmospheric conditions from shot to shot, vibrations of the barrel, recoil and other factors.

These causes cannot be allowed for in advance, nor can they be corrected.

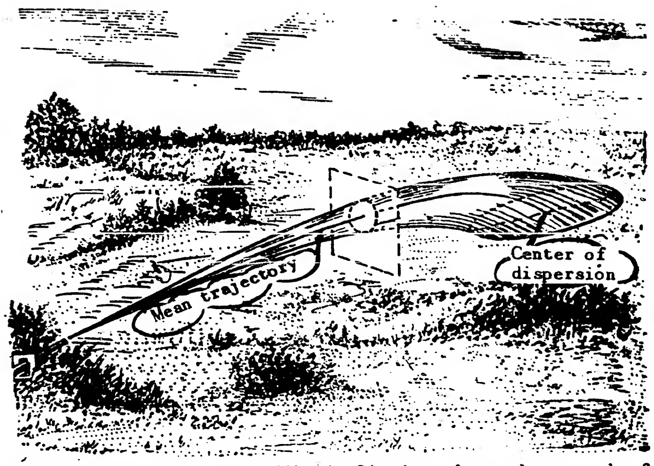

Fig. 151. Firing from the same gun without altering aim produces a sheaf of trajectories, which cluster around a particular mean trajectory.

They are therefore termed chance causes.

If the gunner is firing manually, to there causes must be added the shaking of the gunner's hands, his heartbeat, wavering of the piece due to the gunner's breathing, variations in aim, stronger differences due to recoil, etc.

In firing from an airplane in the air, still other causes may be added: vibration of airplane parts and firing installations, minor fluctuations in flight course, and the decrease in accuracy of sighting due to its complexity. In firing salvos, the piece may be moved from its setting in the vertical or horizontal planes.

The sum total of all these causes results in a considerable scatter of the projectiles from shot to shot, with consequent sharp decrease in the effectiveness of fire, at times even to the point of making it negligible.

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At first blush, it might seem that dispersion is not subject to any regularities and cannot be allowed for in advance. However, such is not the case. The distribution of chance values is subject to definite regularities, which may be studied and put to use or taken into account in practice. Having studied these regularities, the gunner or pilot is in a position to judge beforehand, even before he begins firing, the possibilities of hitting a specific target under given conditions of fire.

What then are the laws governing dispersion?

76. The Law of Dispersion

If we fire a few shots at a target and then attempt to find some kind of regularity in the distribution of the hits, we will fail: their positions will appear to be entirely haphazard.

However, if we fire a large number of shots at the target, the punctures will show a definite distribution. It will immediately be noticed that the area in which the punctures occur is limited. It can also logically be proven that it can not be infinite. However poor the gunner, he will never allow, at a range of say 100 m, a deviation of the bullet from the sight bead exceeding, for example, 2 m. Consequently, if the gunner fires a large number of shots, an area of 4 x 4 m will gradually be filled with hits. This filling of the area will not take place evenly, and the points of impact will tend to cluster in the center of the target and to thin out toward its edges. After a very large number of shots has been fired, the area of hits will have gradually assumed the shape of a circle or elipse flattened vertically or horizontally to varying degrees.

Points of impact in the dispersion area are distributed symetrically in relation to the dispersion center. If we draw a vertical and horizontal line through the center of dispersion the points of impact will occur in equal numbers on both sides of each of these lines. These lines are called, respectively, the vertical

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and horizontal axes of dispersion.

The regularity observed in the distribution of points of impact in the dispersion area is called the law of dispersion.

If we draw straight lines on either side of the vertical and horizontal axes of dispersion and make them parallel to these axes in such a manner that the resulting strips include 25 percent of the total number of impacts, the entire dispersion area will include 8 such strips of equal width in the vertical direction, and 8 in the horizontal. If we count the percentage of impacts in subsequent strips, we will find that it will successively equal 16, 7, and 2 percent.

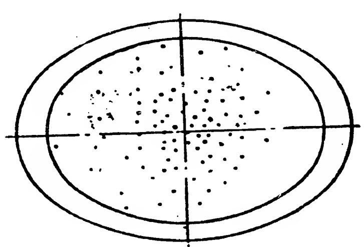

Fig. 152. Hits cluster in an area having the form of an ellipse.

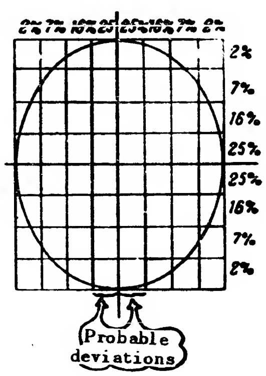

Fig. 153. Each one of the eight vertical and horizontal zones of the ellipsoid of dispersion contains a definite percentage of hits.

The two strips adjoining the axis of dispersion contain the larger portion of impacts, as hits are concentrated in these bands. One half of the width of the band containing the larger half of the impacts is called the horizontal (or vertical, depending on its position) probable deviation.

Probable deviation is represented by the letter B.

To indicate the direction in which probable deviation is taken, the following symbols are used: B_v for probable deviation in height; B_d for probable deviation in range; and B_b for probable lateral deviation. The width of the area of dispersion contains 8 bands, each equal to one probable deviation in width and is therefore designated as 8B.

At their intersections, the vertical and horizontal bands form quadrangles, each one of which contains a definite percentage of hits. This percentage is not difficult to calculate. If, for example, a quadrangle is formed by the intersection of bands containing 16 percent and 7 percent of hits, the quadrangle will contain 16 percent of 7 percent of hits or 7 percent of 16 percent of hits. To find 16 percent of 7 percent, one must divide 7 by 100 and multiply by 16, or, to find 7 percent of 16 percent, one must divide 16 by 100 and multiply by 7, i.e., in both cases the two figures are multiplied one by the other and divided by 100.

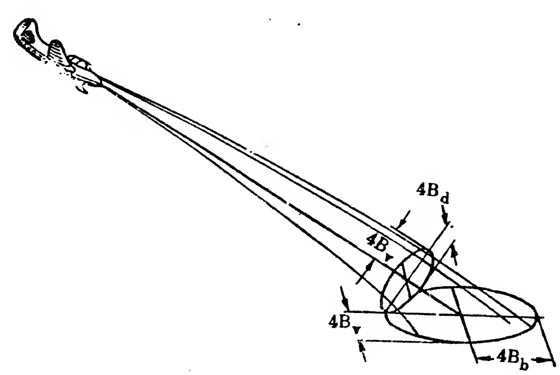

Fig. 154. Probable deviations laterally B_b, in height B_v and in range B_d.

In this case, the percentage of hits in the quadrangle will equal $\frac{16 \times 7}{100} = 1.12$ percent. The percentage of hits in the other quadrangles may be calculated in the same way.

In this way we will obtain a grid giving percentages of hits for each quadrangle. This grid is called the scatter grid.

A scatter grid may be drawn up also on the basis of another principle. If we take vertical and horizontal strips in the ellipse of dispersion, these strips coinciding along their medial edges with the vertical and horizontal axes of dispersion, and containing 70 percent of all hits, we will find that there are three such strips within the ellipse in the vertical and horizontal directions, and that the peripheral strips will each contain 15 percent of all hits. At the intersection of the middle strips at the center of the ellipse we have a quadrangle containing $\frac{70 \times 70}{100} = 49$ percent or, in round figures, 50 percent of all hits. This quadrangle containing that half of hits that shows the greatest clustering and is closest to the center of dispersion, i.e., the better half, if called the heart.

The heart may be imagined as an ellipse, analagous to the full ellipse of dispersion, or as a circle around the center of dispersion whose radius is such as to describe a circumference enclosing the better half of all hits. The radius of this circle is called the probable radial deviation.

The dimensions of the ellipse of dispersion, and therefore the dimensions of the heart, depend on the quality of the weapon, the skill of the gunner, range to target, the complexity of the factors taken into account in sighting, meteorological conditions and other causes.

However, the size of the ellipse of dispersion cannot fall below a certain minimum value which depends on the weapon and its installation.

In actual calculations of the magnitude of dispersion, the deviations in height and laterally are assumed to be equal, i.e., the surface of dispersion is assumed to be a circle. Practice has established certain norms for dispersion

and these norms may be attained by a gunner with average training.

The better the gunner's training, the better he knows his weapon and his sight, the more thorough he is in the upkeep of these, the greater the care with which he stores his ammunition, the better he is trained in sighting and firing, or, if he is the pilot, the better control he has of his airplane, the smaller probable deviation will be when firing. It may in fact be said that the magnitude of the area of dispersion depends mainly on the gunner.

0,04	0,14	0,32	0,50	0,50	0,32	0,14	0,04
0,14	0,49	1,12	1,75	1,75	1,12	0,49	0,14
0,32	1,12	2,56	4,00	4,00	2,56	1,12	0,32
0,50	1,75	4,00	6,25	6,25	4,00	1,75	0,50
0,50	1,75	4,00	6,25	6,25	4,00	1,75	0,50
0,32	1,12	2,56	4,00	4,00	2,56	1,12	0,32
0,14	0,49	1,12	1,75	1,75	1,12	0,49	0,14
0,04	0,14	0,32	0,50	0,50	0,32	0,14	0,04

Fig. 155. Scatter grid. Each square contains a definite percentage of hits.

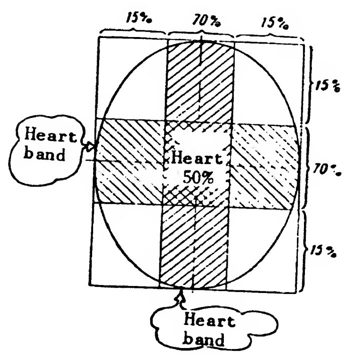

Fig. 156. Heart bands and heart of ellipsoid of dispersion.

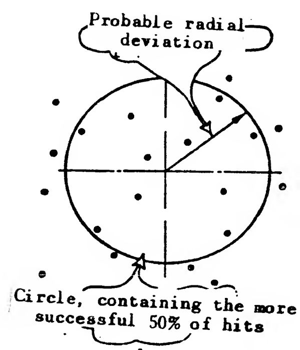

Fig. 157. Probable radial deviation.

77. Compactness and Accuracy of Fire

The skill of the gunner in firing may be judged from the size of the ellipse of dispersion. The more uniform the aim of the gunner, the better he is able to concentrate his hits in the smallest possible area, the more skillful may the gunner be said to be and the greater will be the so-called compactness of his fire.

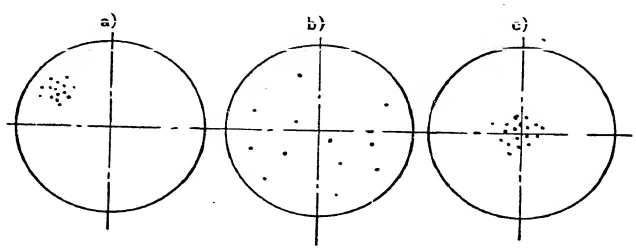

Fig. 158. Compactness and accuracy of fire. a- compact, but poorly aimed fire; b- well aimed, but scattered fire; c- well aimed and compact fire.

In addition to chance causes which result in the usual dispersion, there exist also constant factors affecting equally the flight of projectiles in a given series. Among such causes can figure a wind constant in direction and strength, a defective sight, etc. These causes deflect the course of the projectiles in a constant direction and by a constant amount. Under the action of constant causes, the entire sheaf of trajectories is deflected in the direction in which these causes are acting from the position which it would otherwise occupy.. Constant causes do not affect dispersion, but merely shift the entire sheaf of trajectories in a given direction. The effect of constant causes on the accuracy of fire may be counteracted by the introduction of corresponding corrections into the device used in sighting or in the

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process of sighting itself.

If it is not possible to eliminate the cause of the deflection of the entire sheaf of trajectories, this deflection may be counteracted by changing the setting of the piece by moving it a certain angle in the direction opposite to that of the deflection.

The correct orientation of fire which must be combined with compactness is called accuracy of fire.

In accurate fire, the mean point of hits or dispersion center must coincide with the center of the target, while the dimensions of the ellipse of dispersion must be reduced to a minimum.

Thus, accuracy of fire depends both upon chance causes affecting the magnitude of dispersion and upon constant factors affecting the position of the center of dispersion relative to the center of the target.

To achieve accurate fire, the gunner, in addition to sighting in a uniform manner and thereby decreasing dispersion, must also be able to take into account and eliminate constant causes deflecting the dispersion center from the center of the target.

78. Probability of Hitting Target

If we know in advance the dimensions of the target and the dimensions of the area of dispersion, we may estimate the effectiveness of fire on that target. Let us assume that we are firing from a pistol at a wall measuring 4 x 4 m at a range of 25 m, aiming at the middle of the wall. It is obvious that in this case the size of the ellipse of dispersion cannot possibly exceed the size of the target, and that each shot will reach the target. This means that if the size of the target exceeds that of the ellipse of dispersion all the projectiles released at the target will hit it.

Under the practical conditions of fire on aerial and ground targets, target

dimensions are considerably smaller than those of the ellipses of dispersion that correspond to given conditions of fire, and for this reason only some of the bullets released at the target will reach it. If, for instance, target dimensions are such that the target occupies an area exactly coincident with the heart of the ellipse, only 50 percent, i.e., half of the projectiles aimed at the target will reach it and that only on the condition that a large number of shots is fired.

It should not be assumed that if four shots are fired at the target two of them will necessarily hit it. Of all the projectiles fired at the target, 50 percent will reach it only after a large number have been fired, say 100 or more. Whether single projectiles hit the target depends on chance, and it may be that all of our four projectiles will hit the target or that all four will miss it, or that only one will hit the target, in which case it will constitute not 50 percent, but 25 percent of those fired.

Therefore, in firing upon a target whose dimensions are smaller than those of the ellipse of dispersion, the possibility of hitting the target with a specific number of projectiles can only be estimated with a certain degree of probability. The greater the dispersion, the smaller the dimensions of the target and the greater the deflection of the center of the ellipse of dispersion relative to the center of the target, the lower the probability of hitting the target.

Let us call the probability of hitting the target the expected percentage of projectiles that hit the target of all those fired at it on the condition that a large number of shots be fired.

We must immediately note and remember that the actual percentage of hits in firing will always differ from the probable percentage of hits and only if a very large number of shots is fired will the actual and probable percentages of hits coincide.

In contradistinction to the probability of hitting the target, the actual percentage of hits is termed frequency.

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Let us assume that a card is taken out of a pack at random. The question asked is whether the card removed will belong to a red suit. Since the pack contains an equal number of cards of red and black suits, it is obvious that it is just as likely that the card removed would be red as that it would be black. This means that if we repeatedly removed cards from the pack and put them back each time, half of the cards picked will be red and the other half black. In other words the probability of picking a red card equals one half. If the number of experiments is limited, the frequency will depend on the number of these experiments and the smaller this number the more frequency will differ from probability.

Let us assume that we pick a card only once. The card picked may be red or black. In the first case the frequency with which a red card will appear will equal unity or 100 percent. In the second case frequency will equal zero, and therefore frequency will in no way equal probability. This implies that one single experiment is not sufficient grounds for any conclusion as to the laws governing the occurence of a particular phenomenon (in this case, the appearance of a red card). If we pick a card twice in a row, we may legitimately expect that one of these cards will be red, the other black, since the probability of both kinds appearing is equal. It may happen, of course, that one of the cards will be red and the other black, but it may also happen that they will both be either red or black. In the first case, the frequency of appearance of the red card will equal the probability, and in the second case it will equal unity, i.e., 100 percent, and in the third case it will be zero.

If we pick a card ten times consecutively, it is not very probable that all ten cards will be of the same color. In other words, the frequency of the appearance of red cards will be equal neither to zero nor 100 percent but will approach 50 percent closer than it would in two or three experiments.

If we pick a card one hundred times it is already quite impossible that the hundred should either all be red or black. The number of cards of both colors will

be very close to 50. After a very large number of experiments, the percentage of red cards picked will equal that of the black cards.

Applying our reasoning in the field of aerial gunnery, we may say that if the probability of hitting the target is known to us, the number of actual hits will equal the probable number only if a considerable number of shots is fired. For a small number of shots, the number of actual hits may be above or below the expected number.

Why then should we bother with this question, if the number of actual hits will differ from the number expected and if a knowledge of the probability of hitting the target is in itself no indication as to whether the target will be hit or not?

It has been found that the ability to calculate the probability of hitting the target allows the solution of a whole series of practical problems, particularly in bombing and firing.

If the probability of hitting the target is known, it is always possible to estimate approximately how many projectiles will be needed, how many approaches to the target should be made and how many airplanes should be assigned to knocking out the target.

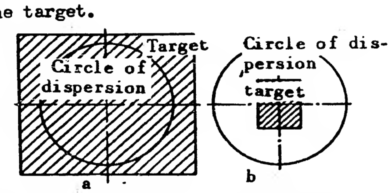

Fig. 159. Probability of hitting the target. a- if the dimensions of the target exceed those of the circle of dispersion, all projectiles hit the target; b- if the dimensions of the target are smaller than those of circle of dispersion, only some projectiles hit the target in that case.

If, for instance, the probability of hitting the target under given conditions of fire equals 5 percent, and if no less than 6 hits are needed to knock out the target, it will be necessary, in order to hit the target even with one projectile to fire as many times as 5 percent goes into 100 percent, i.e., $\frac{100}{5} = 20$ times; to have 6 projectiles hit, it will be necessary to fire 6 times as many shots, i.e., $20 \times 6 = 120$ shots. If, in the course of a single

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attack, the gunner can fire only some 30 shots, this means that to knock out the target the plane must make 4 approaches, or that 4 planes must consecutively attack.

In the actual course of attack, it may happen that the target will be knocked out in the first approach, but it may also occur that even 5 approaches will not suffice. This depends on a whole series of chance causes which cannot be predicted.

However, if the number of attacks is very large, each 4 attacks will lead, on the average, to 6 hits on the target. Therefore, a knowledge of the probability of hitting the target and the number of hits required to knock it out allow necessary preliminary calculations.

It may also be noted that the standards used in evaluating practice fire are also derived from the theory of probability.

On what, then, does the probability of hitting the target depend?

The probability of hitting the target depends primarily on the relationship between target size and the size of the ellipse of dispersion. The greater the area of the target, the greater the probability of knocking it out.

The probability of hitting the target will decrease if the center of the ellipse of dispersion moves relative to the center of the target. When there are no constant causes tending to shift the entire sheaf of trajectories in relation to the target, or when such constant causes are taken into account by the gunner, the center of dispersion coincides with the point at which the gunner is aiming to direct the flight of the projectiles. If the gunner is not aiming his projectiles at the center of the target, or if he has not allowed for constant factors deflecting all trajectories from the center of the target, then the center of dispersion will shift away from the center of the target and the target itself will be moved to those parts of the ellipse of dispersion which receive smaller numbers of hits. If it happens that the center of dispersion is situated outside of the boundaries of the target at a distance equal or greater than 4 probable deviations, not a single projectile will hit the target. Thus, the probability of hitting the target

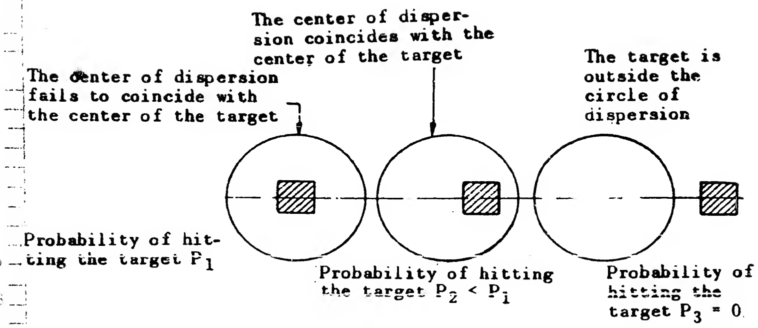

Fig. 160. As the center of dispersion is shifted away from the center of the target, the probability of hitting the target decreases.

depends not only on the dimensions of the target relative to the dimensions of the ellipse of dispersion but also on the position of the target in the ellipse, i.e., on the extent to which the center of dispersion is shifted away from the center of the target.

Numerically, the probability of hitting the target may be expressed as the relation between the number of projectiles hitting the target and the total number of projectiles released at it. Thus, if we say that the probability of hitting the target is 1/4 or 3/5, this means that in the first case of every 4 projectiles released at the target one, on the average, will hit it and, in the second case, out of every 5 shots 3, on the average, will result in hits. All this, of course, applies only if there is a large number of shots.

The probability of hitting the target may also expressed as a percentage. To do this we need to know the percentage of projectiles that hit the target as compared to the total number released. In our examples, the denominators of the fractions stand for the total number of projectiles released, i.e., 100 percent, while the numerators represent the number of projectiles that have reached the target.

i.e., p percent. By converting the proportions we get, in the first instance,

$$\frac{1}{4} = \frac{p}{100}, \text{ whence } p = \frac{1}{4}\,100 = 25 \text{ percent},$$

and, in the second case,

$$\frac{3}{5} = \frac{p}{3}, \text{ or } p = \frac{3}{5}\,100 = 60 \text{ percent}.$$

Thus, a probability of hitting the target equaling 1/4 is the same as a probability of 25 percent, while a probability of 3/5 is a probability of 60 percent.

The probability of hitting the target expressed in percentages is called the probable percentage of hits.

If the number of shots fired is small, a knowledge of the probable number of hits does not allow predicting the effects of fire, but does allow a somewhat reliable estimate of the number of hits for a given number of shots at the target.

In order to judge the possibility of knocking out the target with a given number of shots, it is necessary to be able to determine the probability of hitting the target.

79. How to Determine the Probability of Hitting the Target in Aerial Gunnery

The probability of hitting the target may be determined on the basis of the law of dispersion, the size of the ellipse of dispersion, the size of the target and the position of the center of dispersion relative to the target.

There are several methods for calculating this probability and the one used depends upon the shape and the size of the target.

The most accurate, and at the same time the most cumbersome, is the so-called method of probable deviations. In estimating the probability of hitting the target by this method, it is assumed, for the sake of simplicity, that the area of dispersion in a plane perpendicular to the direction of fire has the form of a circle, and that the center of dispersion coincides with the center of the circle.

To determine the probability, it is necessary to know the projection of target

Probability of hitting the target

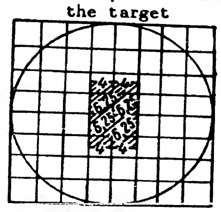

Fig. 161. The probability of hitting the target may be determined by superimposing a scatter grid over the target.

dimensions on the surface of the circle of dispersion. If we draw the target (in the perspective in which it is seen by the gunner) and the scatter grid on the same scale, and superimpose the scatter grid over the target in such a way that the point of intersection of the dispersion axes (i.e., the center of the circle of dispersion) coincides with the center of the target or with the point of aim on the target, we may then, by adding the percentages for the quadrangles covering the target, calculate the total probable percentage of hits on the target. The percentage for each quadrangle must be taken in its entirety if the quadrangle covers the target in its entirety and in part if the quadrangle covers the target in part, the part depending upon the extent to which that quadrangle covers the target. The dimensions of the target are usually known with a certain degree of accuracy, while the dimensions of the ellipse of dispersion may be taken from a special table in accordance with the conditions of the attack and the range of fire. To draw the scatter grid, a square is required, measuring 8 probable deviations vertically and horizontally as determined from a table; this square should accordingly be divided into 8 horizontal and vertical bands, and the corresponding percentages of hits entered in the 64 resulting squares.

In cases where the target fits entirely in the heart of the circle of dispersion, the so-called heart method method is used. In this method, it is assumed that impacts are evenly distributed over the heart surface and that the percentage of hits on the target will be smaller than the percentage of hits in the heart area

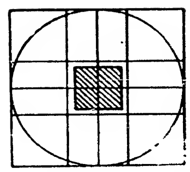

Fig. 162. If the target fits in the heart of the dispersion area, the probability of hitting the target may be found by comparing the surfaces of the target and of the heart.

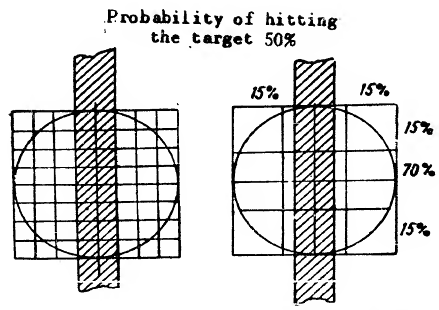

Fig. 163. If the target is of such a length as to exceed the diameter of the circle of dispersion, the probability of hitting it may be found by reference to the heart band or by the calculation of probable deviation.

by as many times as the surface of the target is smaller than that of the heart.

If the target is of such a length as to exceed the diameter of the circle of dispersion, while its width is inferior to the width of the heart band, it is possible to estimate the probability of hitting the target by the heart band method. In this case as well, it is assumed that impacts are evenly distributed in the heart band and that the percentage of hits on the target will be smaller than the percentage of hits in the heart band by as many times as the surface of the target is smaller than that of the heart band. As examples of such long targets, we may cite railway transport, infantry columns, trenches, convoys, etc.

The probability of hitting the target does not in itself determine the number of expected hits, which depends rather upon a series of other causes and conditions of fire.

80. How to Determine the Number of Expected Hits on the Target

It is possible to determine the number of expected hits on aerial or ground targets only if the number of bullets or shells released at the target is known and if it is known whether all the bullets and shells fired will be involved in knocking out the target.

The number of shells or bullets released at the target from an airplane depends on the time spent firing, the number and the firing speed of the machine guns and cannons participating simultaneously in fire on the target. The duration of fire depends in turn on the conditions under which the firing takes place.

When firing on a stationary ground target or an aerial target at a foreshortening of number 0/4, the pilot or gunner must use tracking fire until closeness to the target requires the cessation of fire and break-away. All the shells and bullets released when firing under such conditions may be involved in knocking out the target.

When firing on a target whose foreshortening is 2/4 or more, the gunner or pilot as we have already seen, can use only barrage fire in the form of separate salvos and allowing the target to pass through the sheaf of trajectories at each salvo. In fire of this type, not all the shells or bullets released may participate in knocking out the target, since the only ones involved will be those crossing the surface of the ellipse of dispersion (situated at the same range as the target) at the time the target crosses the sheaf of trajectories. The number of bullets and shells involved will be greater to the extent that the interval of time spent by the target in the sheaf is greater; in turn, the smaller the foreshortening of the target, the longer it will remain within the sheaf of trajectories.

Let us agree to call the bullets and shells of the salvo that may be involved in knocking out the target effective bullets or shells and represent their number as N.

By knowing the probability of hitting the target and the number of effective

bullets in the salvo, we may determine the average number of expected hits or, as it called, the mathematically expected number of hits.

If all the bullets in a salvo are effective, the mathematically expected number of hits will equal the probability of hitting the target. If, for instance, this probability equals P and the number of effective projectiles in the salvo is N, the mathematically expected number of hits will be found by the following reasoning: the probability of hitting the target is the percentage of all bullets released that will strike the target; therefore, if the number of effective bullets if N, one percent of this figure will be $\frac{N}{100}$ and p percent will be $\frac{pN}{100}$. This means that the mathematically expected number of hits will be

$$M.\ E. = \frac{pN}{100}.$$

This formula is valid only in those cases in which the probability of hitting the target is equal for all bullets. This can be true only when the target does not move in the trajectory sheaf perpendicularly to the direction of fire, i.e., when fire is on a stationary ground target or an aerial target at a foreshortening of 0/4. If the target is crossing the sheaf of trajectories, the first effective bullet released will have an insignificant probability of hitting the target, since at the moment the target is only barely entering the ellipse of dispersion. Subsequently, the probability of hitting the target will increase for later bullets as the target approaches the center of the sheaf of trajectories, and will then decrease as the target begins to leave the ellipse of dispersion. Designating the probability that the first effective bullet of the salvo will reach the target by p_1, that of the second effective bullet by p_2, that of the third by p_3, and so on, to p_N, representing the probability for the last bullet in the salvo, we will obtain the entire probability in the form of the sum of the probabilities for separate bullets, i.e.,

$$P = p_1 + p_2 + p_3 + \dots + p_N.$$

The mathematically expected number of hits will then be:

$$\text{M. E.} = \frac{(p_1 + p_2 + p_3 + \cdot \quad \cdot + p_N)}{100} N.$$

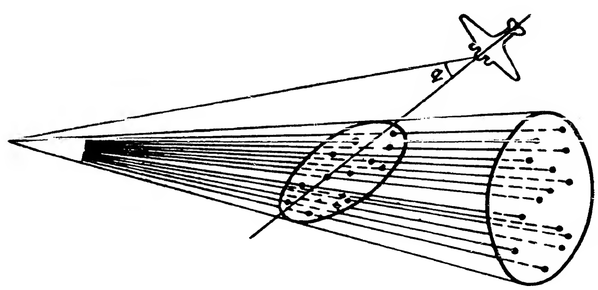

Fig. 164. Passage of target through a sheaf of trajectories.

So as not to have to calculate the probability separately for each bullet of the salvo, it is assumed by approximation that the expected number of hits in a target moving through the ellipse of dispersion is one half the number expected if the target is motionless.

$$\text{M. E.} = \frac{1}{2}\,\frac{pN}{100} \quad \text{or M. E.} = \frac{pN}{200}.$$

Thus, it is always possible to determine with a certain degree of accuracy the expected number of bullets in a salvo which will reach the target. It may be noted that the expected number of hits in barrage fire is found to be very small.

In conclusion, we may note that all our reasoning concerning the trajectory of the projectile, set forward points and corrections for the effects of various factors on the accuracy of fire must be considered, now that we know about disper-

sion as applying to the mean trajectory of the projectile, since no single trajectory can ever be calculated exactly due to the effect of chance causes.

Here we will conclude our examination of fire on the basis of an allowance for absolute target velocity. The chapter on dispersion applies in full to cases of fire on the basis of an allowance for relative target velocity, with only minor modifications, of which we shall speak later.

Let us now, then, pass on to a type of fire quite different from the one examined already, and study the practical conclusions to be drawn from it.

PART THREE

FIRE ON THE BASIS OF ALLOWANCE FOR RELATIVE TARGET VELOCITY

We now make the acquaintance of a specialized and very interesting branch of aerial gunnery, the theory of fire on the basis of allowance for relative target velocity.

It is concerned with the solution of the same problems as those examined in the first part of this book, but by means of an entirely different and highly original approach involving an allowance for the apparent, or, to put it more simply, the seeming, motions of the target and of the projectile.

Taking into account this apparent motion of the target, which does not actually exist for the stationary observer, leads to quite unexpected and unusual results. One cannot help but be surprised that fire on a target whose actual velocity and direction of motion are not taken into account at all can lead to results which are as accurate and as effective as when these factors are allowed for.

It is indicative that, up to the present time, it has not been possible to design an automatic sight which would take into account absolute target velocity, while automatic sights designed on the principal of an allowance for relative target velocity have been in existence for a relatively long time despite the fact that this branch of the theory of aerial gunnery is relatively new. As long ago as 1940, we had perfected the design of a sight which allowed for relative target velocity and made use of a gyroscopic gauge of angular velocity.

Today, automatic sights are capable of reckoning relative target velocity and are widely used in the air force. These sights free the gunner entirely from the necessity of performing any kind of calculations. The gunner's task is reduced to performing a number of purely mechanical acts which are learned through training in

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sighting with the help of special training devices.

To the extent that a sight simplifies the work of the gunner, its design becomes more complicated, the principles of its construction and operation become more complex and the theoretical basis of its operation becomes harder to understand.

Generally, the concept of relative motion is grasped with a certain amount of difficulty and the concepts of relative angular and linear leads are frequently particularly hard to assimilate.

We will attempt to examine all the problems of fire on the basis of reckoning relative target velocity and consider each new concept in detail as it is introduced.

What then is the nature of fire with reckoning of relative target velocity?

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Chapter I

RELATIVE TARGET VELOCITY

81. How to Find Relative Target Velocity

In the second part of this book we defined mechanical motion as relative motion. We established that the motion of any object may be observed only if it moves in relation to other bodies which are arbitrarily assumed to be stationary, and we called absolute motion motion relative to bodies at rest. As we have already stated, we cannot point to any body in the universe that is at rest. We occasionally observe bodies which appear to be at rest, but appearances are deceptive. Under terrestrial conditions, we may take the Earth as a stationary body. In the same manner, we may take the air, the water in a stream, etc., as stationary bodies and agree to consider absolute any motion relative to them.

The solution of the problem of which body of those around us we may conveniently consider stationary depends on how the problem of motion is posed. If, for instance, we are asked how many kilometers one ship will lag behind another after an interval of two hours, if they are moving in the same direction, one at a speed of 10 km/hr and the other at a speed of 7 km/hr, we will give the answer as 6 kilometers without stopping to think, since in one hour one ship will lag $10 - 7 = 3$ km behind the other and will therefore lag 6 km in two hours. In this case we are not at all interested in the speed of the current relative to the shores of the river. We examine the motion of the ship in relation to the water, assume the water to be stationary, and agree to call absolute the motion of the ships relative to the water.

If the question is asked differently, e.g., how much earlier the faster ship will reach a point situated at a distance of 60 km, we will immediately ask the direction and speed of the river current. If the speed of the current is 5 km/hr

and the ships are moving downstream, their speeds relative to the river bank will be respectively 15 and 12 km/hr and they will cover the entire distance in respectively 4 and 5 hours and one ship will therefore have a lead of one hour over the other.

If the ships are moving upstream, their speeds relative to shore will be 5 km/hr and 2 km/hr and they will cover the distance of 60 km in 12 and 30 hours respectively and the difference in time will be 18 hours.

This example shows clearly that in one case it is sufficient to consider motion relative to the water while in the other case it is necessary to view it as taking place relative to the river bank, i.e., the Earth.

In the first case, we may agree to call absolute motion relative to the water, and relative the motion of the ships in relation to one another. In the second case, the motion of the ships relative to the Earth must be considered absolute while their motions relative to the water and to each other must be considered as relative. The motion of the water and the river relative to the banks in this case is called transfer motion.

In firing at ground targets from the air, the motion of the target, that of the gunner's own plane and that of the projectile are examined in relation to the Earth and considered absolute. Air motion (wind) relative to the Earth is a transfer motion, while the motion of the target in relation to the gunner's plane is relative motion.

In firing upon an aerial target from the air, the motions of the target, projectile and gunner's plane relative to the air are considered absolute, and the air is considered immobile, since its motion relative to the Earth has no effect on the fire. All motions relative to the gunner in aerial gunnery are termed relative motions.

To imagine relative motion, it is necessary to forget one's own motion, to consider oneself stationary, and to examine the motions of all surrounding bodies in relation to oneself. If a gunner in an airplane in flight views a target which

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is following him at a velocity equal to his own, despite the fact that both airplanes may be flying at very high speeds, relative target velocity, i.e., its velocity relative to the gunner, will equal zero. The target is motionless relative to the gunner.

Like any mechanical motion, relative target motion is characterized by its velocity. The velocity of the target's relative motion, or, relative target velocity, is the velocity at which the target moves relative to the gunner. Let us designate relative target velocity as v_r.

To clarify the concept and manner of determination of the magnitude and direction of relative velocity, let us give a few examples.

A passenger sitting in a railroad car moving at a speed of V_1 may think of the train's and his own motion relative to the Earth and the objects surrounding the train or he may assume that he is stationary and that the Earth and surrounding objects are moving toward him at a velocity of V_1. In the first case, the velocity of the train and of the passenger will be an absolute one and its vector will be oriented in the direction of the motion of the train relative to the Earth and will equal $\bar{V}_1$. In the second case, the velocity of the surrounding objects relative to the passenger will be a relative one equal in value to the velocity of the train but oriented in the opposite direction, that is to say, $\bar{v}_r = -\bar{V}_1$.

If a second train is moving in the opposite direction with a velocity of $\bar{v}$, then the absolute velocities of the passenger and the second train will equal respectively V_1 and $-\bar{v}$, oriented in opposite directions. However, the relative velocity of the second train, i.e., the velocity with which it is approaching the passenger, will equal the sum of the numerical values of velocities $\bar{V}_1$ and $\bar{v}$, and will be oriented in a direction opposite to that of the motion of the passenger. This is easy to establish if we imagine the passenger as stationary relative to the Earth. Then, so that the approaching train will have the same velocity as previously stated, it must be imagined that the approaching train has increased

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its velocity by the value minus $\bar{V}_1$, i.e., its relative velocity will equal its absolute velocity minus v added to the velocity of the passenger oriented in the opposite direction.

To determine relative velocities for approaching motion, it is necessary to add to the vector of the velocity of approaching motion the vector of one's own velocity oriented in the opposite direction.

If another train is moving parallel to the observer's at a velocity of $\bar{v}$ oriented in the same direction as that of the observer's motion, the relative velocity of this train may be found by the following reasoning. If the velocity of both trains is equal, relative velocity $\bar{v}_r$ will equal zero, i.e., the train moving alongside the observer will be stationary in relation to him. If the velocity of the second train is less than the velocity of the observer's train, the former will lag behind and its relative velocity will equal numerically the difference between velocities $\bar{v}$ and V_1 and oriented in a direction opposite to that of the observer's motion.

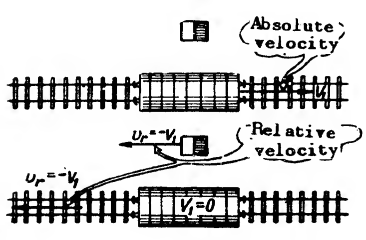

Fig. 165. For actual absolute motion, it is possible to substitute the relative motion of surrounding objects in the opposite direction.

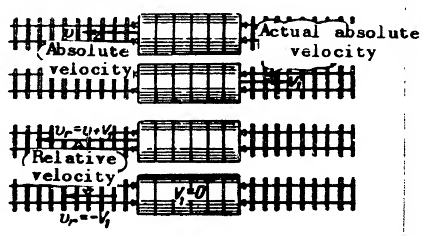

Fig. 166. Relative velocity of train moving in opposite direction found by assuming observer's train to be stationary, and oncoming train as moving at a velocity to which the value of V_1 has been added.

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If the velocity of the second train is greater than that of the observer's train, it will pass the latter and its relative velocity numerically will again equal the difference between velocities $\bar{v}$ and $\bar{V}_1$, but oriented in the direction of the observer's motion.

Let us examine yet one more case of relative motion. Let us assume that a passenger in an automobile is observing the motion of another automobile, moving at an angle to the direction of his own motion (Fig. 169). In this case, how do we

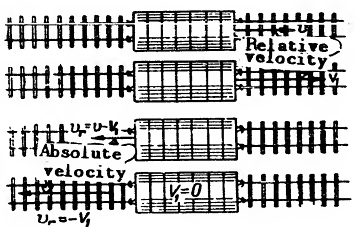

Fig. 167. A train moving in the same direction as the observer appears to be moving in the contrary direction, if its velocity is inferior to that of the observer.

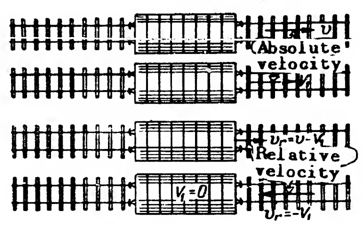

Fig. 168. If the velocity of a train moving in the same direction as the observer exceeds that of the observer, it appears to be slowly moving in the same direction as the observer is moving.

find the relative velocity of the second automobile, i.e., its velocity relative to the passenger?

Let us assume that at a certain initial point in time the observer is situated at point O while the automobile he is watching is at point O_1. If the observer were stationary, the automobile would need one second to cover the distance corresponding numerically to its velocity and to arrive at point A_1. The relative velocity of the automobile would then equal its absolute velocity v. Let us assume that after the automobile has moved to point A_1 it stops, but the observer moves.

In one second the observer, having traveled the distance corresponding to his own velocity, will arrive at point B_1 and will see the automobile in direction B_1A_1. Such are the absolute motions of the observer and the automobile.

To find the relative change in position of the automobile, the observer must imagine himself as stationary and, as before, situated at point O. Then it will seem to him that the automobile is moving toward him from point A_1 at a velocity of $-V_1$, equal to the velocity of the observer and that in one second it travels the distance corresponding to this velocity and arrives at point C_1.

Since the motion of the observer and of the automobile takes place continuously and simultaneous, it will seem to the observer that the automobile is moving along line O_1C_1 at a velocity numerically equivalent to the length of that line.

As a result of this change in position, the observer, who believes that he is located at point O, will think that the automobile is visible in direction OC_1, whereas he is actually located at point B_1 and sees it in direction B_1A_1 parallel to OC_1.

If we now examine these motions for a time interval of 2 seconds, when the second second has elapsed, the automobile will be at point A_2, and the observer will be at point B_2 and will see the automobile in direction B_2A_2. But if the observer does not notice his own motion, it will seem to him that the automobile has moved from point C_1 to point C_2 and that it is seen in direction OC_2. This direction, OC_2 will also be parallel to the true direction to the automobile, B_2A_2.

Thus, the relative motion of the automobile will appear to the observer, who considers himself stationary, as taking place along line $O_1C_1C_2$, and the observer will see the automobile, at first, in direction OO_1 at point O_1, then, in one second, in direction OC_1 at point C_1, in two seconds in direction OC_2 at point C_2, etc. It should be noted that this relative motion of the automobile will appear to be taking place sideways to the observer, i.e., as he would see the motion of a tug from a river bank when the tug is pushed sideways at an angle to its course by

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In one second the observer, having traveled the distance corresponding to his own velocity, will arrive at point B_1 and will see the automobile in direction B_1A_1. Such are the absolute motions of the observer and the automobile.

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wind or current.

In the idiom of aerial gunnery we may now say that the vector of relative target velocity equals in magnitude and direction the geometric sum of the vector of absolute target velocity and the vector of own speed oriented in the opposite direction.

In other words, to find relative target velocity one must mentally arrest the

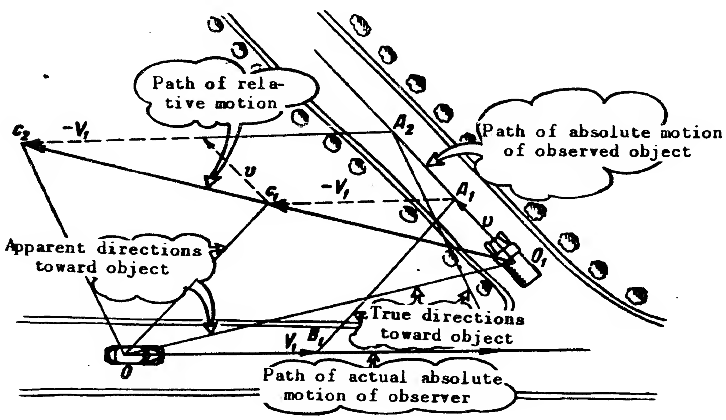

Fig. 169. The observer moving along path OB_2 believes he is stationary and situated at point O, while the observed object appears to move along path O_1C_2, whereas its true motion is along path O_1A_2.

motion of one's own plane and, having turned it around in the opposite direction, "give" one's own motion to the target. Then the geometric sum of target absolute velocity and this "given" velocity will equal in magnitude and direction relative target velocity.

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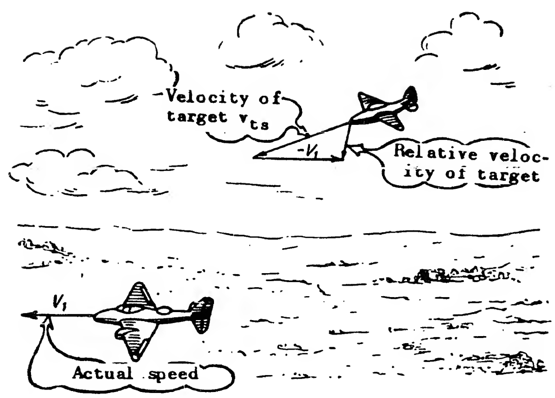

Fig. 170. The relative velocity of the target equals the geometric sum of the vector of the absolute velocity of the target and the vector of actual speed, oriented in the opposite direction.

It should be noted that this method of determining relative velocity is required only for theoretical purposes and that it is not necessary for the airborne gunner, since he sees only the relative motion of the target and has no need geometric formulations.

82. The Concept of Transverse Target Velocity and Velocity of Range Variation

Observation of a target from a plane in flight involves a continuous variation of the direction of the line of sight and of range to the target. If the motion of the target is such that its relative velocity is oriented along the initial line of aim to the target or along the initial line of sight, the direction of the line of aim will not vary with target motion and only the range to the target will vary.

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If the relative velocity of the target is oriented perpendicularly to the initial line of aim, variation in the direction of the line of aim will be at a maximum while range, for all practical purposes, will not vary. Thus, the relative change in position of the target will be greater as the angle between the initial line of sight and the vector of relative target velocity approaches 90 degrees. At angles intermediate between 0 and 90 or 90 and 180 degrees, the relative shift in target position will be greater to the extent that the projection of relative target velocity on a direction perpendicular to the initial line of aim is greater. This projection of relative target velocity on the direction perpendicular to the initial line of sight is called transverse target velocity and is represented as v_p. Therefore, the rate of change of the direction of the line of aim depends on the value of transverse target velocity. We will see further on that transverse target velocity is very important in the calculation of the lead angle and particularly in the setting of the lead angle by an automatic sight.

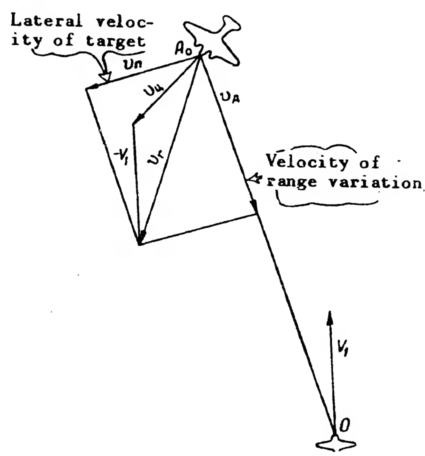

Fig. 171. The relative motion of the target may be seen as motion as a velocity v_d along the line of sight, and a velocity v_p along a line perpendicular to the line of sight.

The variation of range to target also depends on the angle formed by the vector of relative target velocity and the initial line of sight, but in this case the more this angle differs from 90 degrees, the more marked the variation of range to target. If this angle is less than 90 degrees, the range decreases; if it is greater than 90

degrees, range increases.

Let us call the velocity of range variation the velocity at which range increases or decreases and represent it by v_d. In other words, range variation velocity is the velocity at which the target approaches toward or recedes from the gunner's airplane. When the angle between the vector of relative velocity and the line of aim to the target equals zero, i.e., when target velocity is directed straight at the gunner, range will decrease at a velocity equal to relative target velocity. If this angle equals 180 degrees, range will increase at that same velocity. At intermediary angles, range variation velocity is equal to the projection of the vector of relative target velocity on to the line of aim.

Thus, if we decompose the vector of relative initial target velocity in the direction perpendicular to the line of aim and parallel to it, we thereby obtain respectively transverse target velocity and range variation velocity.

These two velocities fully define the motion of the target relative to the gunner.

83. Angular Velocity of Target

Let us imagine that we are observing a target from an airplane in flight through the sight of a mobile gun installation and that we maintain the pipper of the sight on the target. In order to have the target and the pipper coincide all the time, the sight must be turned to follow the target at a speed which will be greater to the extent that the transverse velocity of the target is greater and the range is shorter. That is, if relative target velocity is directed toward the gunner or away from him, i.e., if the transverse velocity of the target equals zero, there will be no need to turn the sight at all and the target will remain at the pipper without the sight having to be moved. As the angle between the vector of relative target velocity and the line of aim approaches 90 degrees, the transverse velocity of the target increases and the sight must be turned faster. As the range

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to target is increased, the speed at which the sight must be turned decreases. When we observe an airplane flying at very high altitudes, it seems to move very slowly, since we need to turn our head only slightly to follow it. When the same plane goes by at a low altitude, it speed appears very high, since we have to turn our head very quickly to follow its motion.

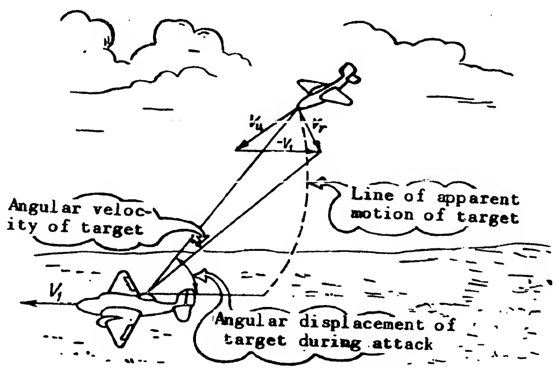

Fig. 172. The angular velocity of the target equals the angle of the rotation of the line of sight in the course of one second, or the angle created by lines ending at the two extremities of the vector of the target's relative velocity.

The angle at which the sight turns in tracking the target defines what is called the angular motion of the target, while the angular velocity of the rotation of the sight defines the angular velocity of target motion.

Let us call angular target velocity the angle over which the line of aim moves within a certain unit of time. The angular velocity of the target may be imagined as the angle over which a thread connecting the target and the airplane of the gunner would move in a given unit of time. Since the thread in this case is, as it were, a radius of rotation of a length equal to the range to the target, while the transverse velocity of the target may be seen as a linear circumferential velocity

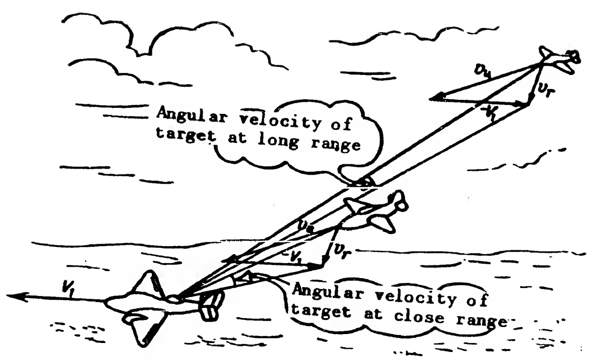

Fig. 173. The angular velocity of the target is inversely proportional to its range.

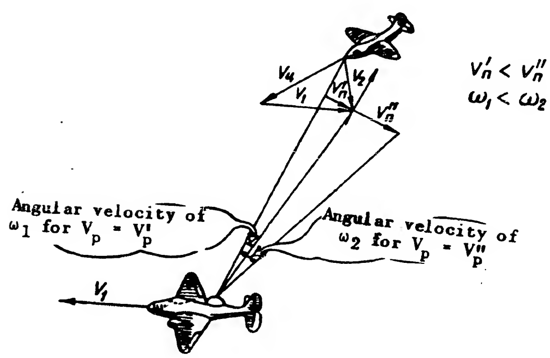

Fig. 174. The angular velocity of the target is directly proportional to its lateral velocity.

it may be inferred in accordance with the mechanical formula $\omega = \frac{v}{R}$ the angular velocity of the target at a given moment equals

$$\omega = \frac{v_n}{D} .$$

This angular velocity changes continuously, since both the range (as a result of range variation velocity) and transverse target velocity vary.

Chapter II

HOW TO MAKE ALLOWANCE FOR RELATIVE TARGET VELOCITY IN FIRING

84. Fire on Parallel Courses of Same Direction

To gain a better understanding of the nature of fire with allowance for relative target velocity, we will begin our study of this method by an examination of a few concrete examples, which we will then follow up with generalizations applying to any relative position of the courses of the target and the gunner's own plane.

One of the simplest situations in sighting arises when one is firing on parallel courses of the same direction (Fig. 175).

Let the plane of the gunner, at an initial moment in time, be located at point O and move at a speed of V_1, while the target, moving at a velocity of v_{ts}, is located at point A_0. The actual speed of the gunner's plane is greater than target velocity. To simplify our reasoning, we will assume that projectile trajectory is rectilinear, and that the projectile travels at an even mean velocity of v_{sr}.

To hit the target, the gunner must set forward the point of aim along the direction of target motion and direct the vector of absolute initial velocity to the set forward point A_u. The time it takes the target to travel from point A_0 to point A_u must equal the time of flight of the projectile from its point of release, O, to that same point A_u.

Since the gunner's own plane is itself moving at a speed of V_1, the bore axis, i.e., the vector of relative initial velocity v_0 must be shifted away from the set forward line in a direction opposite to that of the motion of the gunner's plane at a deflection angle of β. This vector will be oriented toward point A'_u to the rear of the target. The projectile released in direction OA'_u follows line OA_u, the

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direction of which is determined by that of vector v_{o1}, obtained by summing vectors v_o and V_1. Impact of the projectile on the target will occur at point A_u, regardless

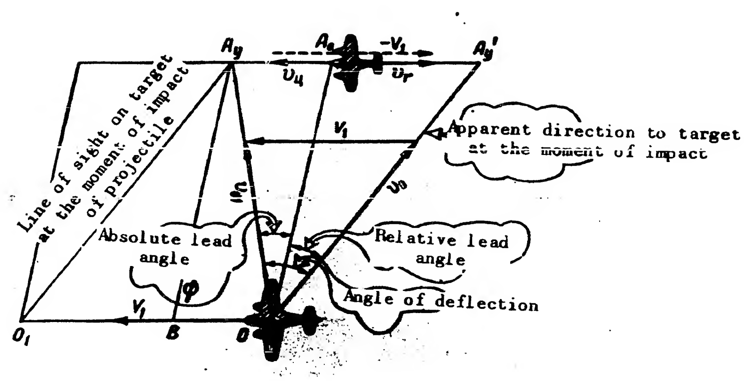

Fig. 175. Fire on parallel courses of same direction. To hit the target, it is necessary either to orient the vector of absolute initial velocity toward the absolute point of impace A_u, or to orient the vector of relative initial velocity toward the relative point of impact A_u'.

of method of sighting.

At the initial moment of time, the gunner sees the set forward point in direction in OA_u and the target in direction OA_o.

During the time it takes the projectile to travel to point A_u, the target will have also reached this point, having covered the distance $A_oA_u = v_{ts}t$. The gunner's plane will be at point O_1, having covered the distance $OO_1 = V_1t$. If the actual speed of the gunner's plane were equal to target velocity, the gunner would see the target all the time in the same direction and when the target reached the set forward point the gunner's plane would have reached point B and direction to target

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would be parallel to the initial direction, i.e., $BA_u // OA_o$. The target would be stationary relative to the gunner. But since $B_1 > v_{ts}$ and the gunner's plane reaches point O_1, the direction to the target at the time of impact will be O_1A_u and the target will lag behind the gunner at a distance equal to segment O_1B. This lag is easy to determine by subtracting the path traveled by the target from that traveled by the gunner's plane. It is not difficult to see that the target will lag at a distance equaling the product of the difference between target and actual velocity and the time of flight of the projectile, i.e., the product of relative target velocity and projectile flight time.

$$O_1B = (v_u - v_1)t = v_r t$$

Since the gunner is not aware of his own motion and believes himself to be stationary at point O, it will seem to him that the target is moving not in the direction of his own flight but backwards toward his tail and that the impact of the projectile takes place at a point lagging behind point A_o at a distance of $A_oA_u' = O_1B = v_r t$.

It is easy to see that the vector of projectile initial velocity is directed toward the apparent point of impact, i.e., that it coincides with the direction of the line of aim at the moment of impact. A very interesting conclusion may be drawn from this.

To hit a target moving on a parallel course it is necessary either to orient the vector of absolute initial velocity v_{o1} to point A_u or to direct the vector of relative initial velocity v_o toward the apparent set forward point A_u'.

We must emphasize once again that the impact of the projectile will take place at point A_u, since, to orient vector v_o toward point A_u' is the same as directing vector v_{o1} to point A_u, as the projectile, in any event, follows line OA_u, propelled by its own velocity.

Let us now examine another case of target motion relative to the gunner.

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85. Fire on Parallel Courses of Opposite Direction

Let the target be traveling on an approaching course (Fig. 176). To hit this target the gunner must direct the vector of absolute initial projectile velocity toward point A_u and the segment A_oA_u must equal $v_{ts}t$.

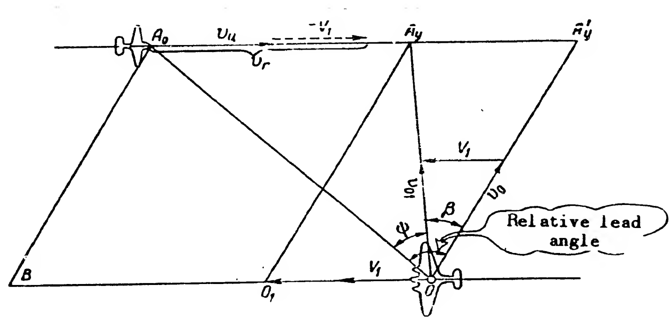

Fig. 176. Fire on parallel courses of opposite direction. The target is hit if vector v_{o1} is oriented to point A_u, or if vector v_o is oriented to point A'_u.

To orient the vector of absolute initial velocity to point A_u, it is necessary to move the vector of relative initial velocity in a direction opposite to that of the motion of the gunner's plane at the deflection angle β; vector v_o will then be oriented toward a certain point A'_u.

While the projectile is traveling, the target will cover a distance $A_oA_u = v_{ts}t$, while the gunner's plane will have covered a distance $OO_1 = V_1t$. Thus, at the moment of impact, the target will be at point A_u and the gunner's plane will be at point O_1. Initially, the gunner saw the target in direction OA_o, but at the moment of impact he sees it in direction O_1A_u.

Let us find out how much the target has moved in relation to the gunner. To do this, let us draw through point A_o a right line $A_oB//A_uO_1$. The relative shift of the target will then obviously equal $OO_1 + O_1B$, i.e.,

$$OB = v_{ts}t + V_1t = (v_{ts} + V_1)t,$$

but

$$v_{ts} + V_1 = v_r$$

so

$$OB = v_rt.$$

In fact, if the gunner were stationary, the relative motion of the target would equal $A_oA_u = O_1B$. However, the gunner is furthermore moving in an opposite direction for a distance of O_1O. Therefore, the total motion of the target will equal the sum of the motions of the target and of the gunner. It is not difficult to see that distance $A_uA'_u = OO_1$, since the motion of the gunner for a distance of OO_1 may be substituted for by an equal displacement of the target in the opposite direction.

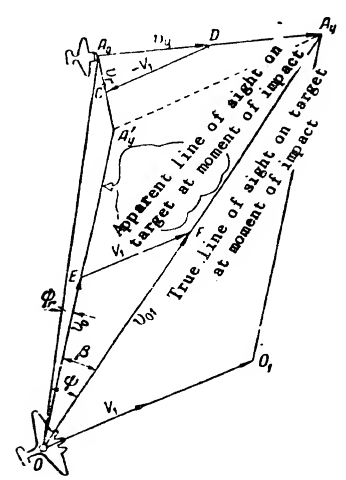

Fig. 177. Sighting diagram for fire on interception courses of same direction.

The gunner considers himself as being at point O and therefore direction OA'_u will seem to him to be direction O_1A_u, while the point of impact A_u will appear at A'_u. The apparent displacement of the target will equal $A_oA'_u$.

We come once again to the same conclusion: that to hit the target we must direct the vector v_o at point A'_u or vector v_{o1} at point A_u.

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86. Fire on Intersecting Courses of Same Direction

At the initial moment in time the target is at point A_o and the gunner at point O (Fig. 177).

To hit the target vector v_{o1} must be directed at the set forward point A_u.

While the projectile travels from its point of release O to the set forward point A_u, the target will have traveled a distance $A_oA_u = v_{ts}t$ and the gunner's plane will have traveled a distance $OO_1 = V_1t$.

At the moment of impact, the gunner will be at point O_1 and will see the target in direction O_1A_u. Since the gunner is not aware of his own motion and considers himself still at point O, the relative target motion will appear to him as follows.

While the projectile is in flight, the target will reach point A_u. Since the gunner's own motion appears to him as a displacement of the target to the side opposite to that toward which he is moving, it will seem to him that the target has moved from point A_o to point A_u' and that the impact occurred at the latter point. In actuality, however, the gunner, located at point O_1, sees the impact at point A_u. It is easy to show that the distance between initial point A_o and the apparent point of impact A_u' equals the product of relative target velocity and projectile flight time. To do this, let us draw a line $CD // \bar{V}_1$ through the extremity of vector v_{ts}. The similitude of triangles A_oCD and $A_oA_u'A_u$ allows us to demonstrate that segment CD equals the vector of actual speed and that therefore segment A_oC, equal to the sum of vectors $A_oD = \bar{v}_{ts}$ and $DC = \bar{V}_1$, equals relative target velocity v_r.

The similitude of these same triangles allows us to prove that $A_oA_u = v_rt$. We find again that, to hit the target, it is necessary either to direct vector v_{o1} to point A_u or vector v_o to point A_U'.

Let us examine still another case.

87. Fire on Intersecting Courses of Opposite Direction

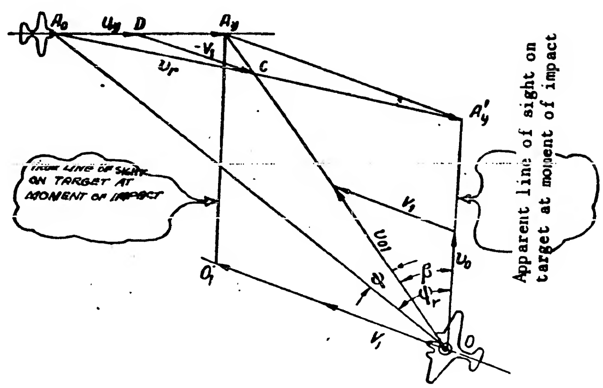

Fig. 178. Sighting diagram for fire on interception courses of opposite direction.

Let us repeat the reasoning that we used in the preceding three cases.

While the projectile is in flight, the target moves to point A_u while the gunner moves to point O_1 (Fig. 178).

Relative target motion may again be seen as its motion at a velocity of v_{ts} from point A_o to A_u and a motion at a velocity of $-V_1$ from point A_u to point A_u'.

The gunner, having moved while the projectile was in flight, from point O to point O_1, will see the target at the moment of impact in direction O_1A_u at point A_u.

But since the gunner considers himself stationary and situated at point O, it will seem to him that point A_u is located at point A_u' and is seen along line OA_u'.

An examination of similar triangles $A_oA_uA_u'$ and A_oCD will make it easy to demonstrate that in this case segment

$$A_oA_u' = v_rt.$$

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From the above examples we are in a position to draw certain conclusions.

88. General Conclusions on the Principles of Fire with Allowance for Relative Target Velocity

Conclusion 1. To hit an aerial target when firing from a mobile installation, it is necessary either to orient the vector of absolute initial velocity v_{o1} toward a point situated at a distance of $v_{ts}t$ forward of the target or to orient the vector of relative initial velocity v_o to a point situated on the prolongation of the vector of relative target velocity at a distance $A_oA_u' = v_rt$.

Conclusion 2. In either of these methods of sighting, the true point of impact is always situated on the course of the target at a distance $v_{ts}t$ from initial point A_o.

Conclusion 3. As a result of the actual motion of the gunner's plane, the apparent point of impact is situated on the prolongation of the vector of relative target velocity at a distance v_rt from the initial point.

Beginners who undertake the study of the theory of aerial gunnery with allowance for relative target velocity often acquire the mistaken impression that in some cases aiming forward along the course of the target with account of the targets absolute velocity and aiming backward along the line of the target's apparent (relative) motion with account of its relative velocity cannot lead to one and the same result, i.e., to hitting the target.

This misunderstanding arises most frequently in analyzing fire on parallel courses of the same direction and intersecting courses of the same direction in cases when actual speed exceeds target velocity.

Let us point out the fundamental difference between the two methods of fire.

In firing upon aerial targets from mobile installations, it is necessary to take into account both target velocity and the actual speed of the gunner's plane.

If absolute target velocity is taken into account, actual speed, as we have

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already seen, is reckoned by means of a special device forming a vectorial triangle of velocities. The sight axis, in that case, lies in the same vertical plane as vector v_{o1} and when aimed at the set forward point, the bore axis of the piece is turned in a direction opposite to that of flight at an angle equal to the angle of deflection. Actual speed V_1 is reckoned automatically by the gunner's plane and the gunner has only to reckon by eye, with the help of his sight rings, the velocity of the target.

If relative target velocity is taken into account, then, as we have just seen, the gunner must orient the vector of relative initial projectile velocity toward the apparent point of impact. The sight axis must be oriented along the bore axis, i.e., along vector v_o, and whenever the gunner directs the sight axis at any given point, vector v_o is likewise oriented toward that point.

At first it might seem that thereby the actual speed of the gunner's plane is not taken into account.

This neglect of actual speed is only apparent, since the gunner, by taking into account relative target velocity, is thereby taking into account both target velocity and his own actual speed, since relative velocity is obtained as a geometric sum of the vector of target velocity and the vector of actual speed.

Since the gunner considers himself as stationary, he must compensate for his motion relative to the target and he does this, as it were, by imparting his speed to the target and assuming that the target is moving at its own velocity v_{ts} and at the velocity V_1 of the gunner's plane oriented in the opposite direction. This leads to one more conclusion.

Conclusion 4. The actual speed of the plane is taken into account by the gunner by eye in form of relative target velocity into which the actual speed of the gunner's plane enters as a component.

89. The Relative Correction Triangle and Its Components

In all the cases of fire with allowance for relative target velocity examined by us, a triangle $OA_oA'_u$ was formed. This triangle may be formed directly without the use of elements of the absolute correction triangle.

Let the target be at point A_o and the gunner at point O (Fig. 179). Target velocity is v_{ts} and the actual speed of the gunner's plane is V_1.

By drawing the tirangle of vectors A_oBC, we will find the vector of relative target velocity v_r.

Along this vector let us measure from point A_o a distance $L_r = v_{rt}$. We get point A'_u. Drawing right lines OA_o and OA'_u from point O we obtain triangle $OA_oA'_u$. By forming this triangle, we are taking into account relative target velocity. The gunner considers himself as remaining all the while and sees the target as moving along line $A_oA'_u$ at a velocity of v_r. Impact takes place at the apparent point of impact A'_u.

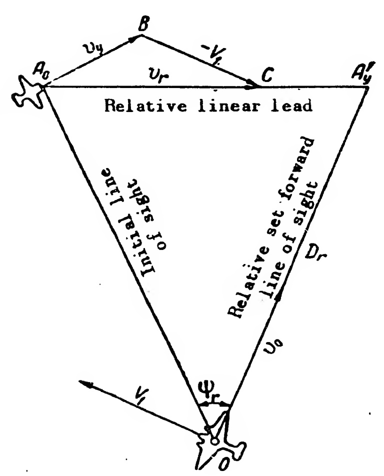

Fig. 179. Relative correction triangle.

Triangle $OA_oA'_u$ is called the relative correction triangle. Let us define the components of this triangle.

The apparent point of impact A'_u is called the relative point of impact or the relative set forward point. The apparent motion of the target takes place along the straight line $A_oA'_u$, and the target may move along this line in any position (tail forward, sideways,

etc.), so that the fore and aft axis of the target need not coincide with the line of apparent motion.

The distance covered by the target relative to the gunner during the time of flight of the projectile, or the distance between initial point A_o and the relative point of impact A_u' is called relative linear lead. Relative linear lead is equal to

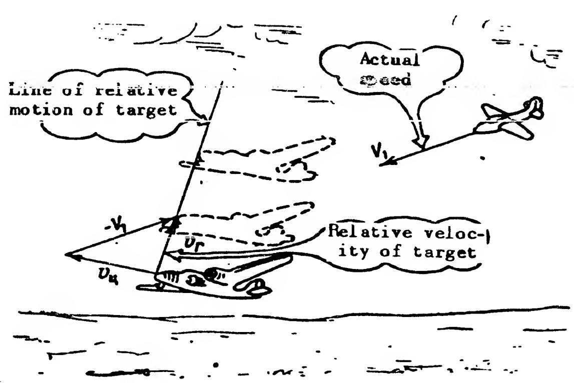

Fig. 180. Relative motion of target during aiming. The target axis does not coincide with the line of its apparent motion.

the product of relative target velocity and projectile flight time:

$$L_r = v_r t.$$

The straight line joining the point of release O with the relative point of impact A_u' is called the relative set forward line of sight, and the distance between these points is called the relative range of fire D_r.

If we turn the initial line of sight to follow the target, in the interval during which the projectile is in flight, it will have pivoted at the point of release O at an angle ψ_r. The angle at which the line of sight turns during

the angle enclosed between the initial line of sight and the relative lead line of sight is called the relative lead angle.

90. The Relative Lead Angle and its Computation

We see that in order to fire with allowance for a relative target velocity it is necessary to know the relative lead angle. In sighting the barrel of the gun must be deflected, i.e. the vector of the relative velocity of the projectile, from the initial line of sight at an angle equal to the relative lead angle, in the direction of the relative shift of the target.

We defined the lead angle as an angle at which the line of sight turns during the flight of the projectile. Once we know the angle velocity of the sight, or, in other words, the angle at which the line of sight turns within a certain unit of time, it is easy to establish the lead angle by multiplying the angle velocity of sight by this time, provided that we know the time of the flight of the projectile:

$$\psi_r = \omega_s t.$$

By substituting the ratio of the lateral velocity of sight and the distance of firing for the expression of the angle velocity of sight we obtain the following formula:

$$\psi_r = \frac{v_n}{D} t.$$

If we divided the numerator and the nominator of our formula by "t" we would get:

$$\psi_r = \frac{v_n}{\frac{D}{t}}.$$

Since $\frac{D}{t}$ is the mean velocity of the projectile in flight v_{cp}, the angle ψ_r is defined according to this formula in radians. Usually, it is expressed in one thousandths:

$$\boxed{\psi_r^T = 1000 \frac{v_n}{v_{cp}}}.$$

Thus, the relative lead angle is directly proportional to the lateral velocity of sight and inversly proportional to the mean velocity of the projectile in flight.

It follows that it is necessary to determine either the lateral velocity of sight or its angle velocity in order to establish the angle of lead.

In the theory of sighting the formulas of the linear lead and the angle of lead have the term $\frac{v_u}{v_{cp}}$ as a multiplicator on the basis of calculating the absolute velocity of sight. In one case, it is multiplied by the distance of fire D to obtain the linear lead and in another – by the sine of the target angle, i.e., by the foreshortening of the target so as to obtain the angle of lead. In both cases the vector of absolute initial velocity of the projectile is directed at the point of lead determined by the angle or by the linear method. That means that the velocity of sight and the actual speed of the aircraft are taken into account separately while the formula of the linear and angle lead accounts only for absolute velocity of sight.

The formula of the relative angle of lead takes into account simultaneously both the actual speed of the aircraft and the velocity of sight, in the form of lateral velocity of sight obtained by resolving the relative velocity while the latter is obtained from the geometric summing of the velocity of sight and the actual aircraft speed. Thus, there is no need to take into account the actual aircraft speed to determine the relative angle of lead with the help of the above formula since it is already incorporated in this formula and the relative initial velocity or – the gun barrel must be directed at the established point of lead.

91. Relative Trajectory of the Projectile

In order to determine the relative angle of lead we proceed under the assumption that the trajectory of the projectile is rectilinear and its motion along the trajectory is uniform.

Assuming again that the projectile is not subjected to the effect of gravity let us examine its motions in relation to the gunner with consideration that the velocity of the motion of the projectile diminishes continuously under the action of the force of air resistance.

Let us assume that a projectile is released in direction OA_o (Fig.181) from an aircraft travelling with velocity V_1. Under the action of the actual speed of the aircraft the projectile in flight will not follow this direction but will move along straight line OA_y in the direction of the vector of absolute initial velocity v_{o1}, obtained as a result of adding vectors v_o and v_1.

If the absolute velocity of the projectile remained constant all the time, the projectile would be in point b_1 within a second and in point b_2 within two seconds, etc. passing every second through identical sections on its course. Consequently,

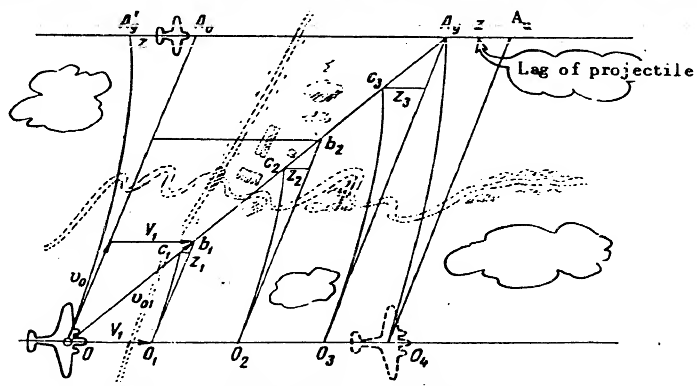

Fig. 181 Lag of projectile. The decrease of the velocity of the projectile in flight results in its apparent deflection aft of the aircraft.

the gunner would find himself in points O_1, O_2, etc. in the same intervals. The direction of the projectile --as the gunner would see it-- would remain the same, i.e. parallel to vector v_o, since $O_1b_1 \| O_2b_2 \| O_3A_y \| v_o$. At the time, when the projectile hits the target the gunner would be in point O_3. It would appear to him that the projectile follows the line of fire in the direction of the vector of the relative initial velocity of the projectile. Since the gunner believes he is stationary and remains in point O, he assumes that the projectile follows line OA_o with velocity v_o.

Since the absolute velocity of the projectile v_{01} continuously decreases, the projectile does not follow the course that is numerically equal to the absolute initial velocity one second after it has been released, i.e. does not reach point b_1 but is in a certain point c_1. It would appear to the gunner watching the flight of the projectile that the projectile departed from the relative line of deflection that is opposite the flight of the aircraft at a distance z_1. The trajectory of the projectile would appear as a curve on a horizontal plane. Two minutes later, when the gunner's aircraft advancing evenly arrives at point O_2, the projectile will be at point c_2 without reaching point b_2 and at an even greater distance than to point b_1 during the first second, since its velocity has been continuously decreasing. The apparent deflection of the projectile z_2 would be even greater. If we assumed that the projectile is deflected in the direction of point A_y, the gunner would arrive at point O_3 before the projectile has reached point A but when it reaches it, the aircraft would be already at point O_4 and the departure of the projectile from the relative line of deflection apparently moving along with the gunner would be $AA_y = z$.

The gunner who would consider himself to be at point O, sees the movement of the projectile along line OA_y while it would seem to him that point A — that has shifted in relation to him — is at distance A_yA_y.

The phenomenon of the apparent deflection of the projectile from the relative base of deflection is known as the phenomenon of lagging.

The curve along which the projectile travels in relation to the gunner is called the trajectory deflection of the projectile.

If we considered also the gravity, the relative trajectory of the projectile is a line of double curvature: it is curved at the plane of the velocity triangle as a result of decreased velocity of the projectile under the action of the force of air resistance and at the vertical plane under the effect of gravity.

The distance from the relative deflection base to the relative trajectory of the projectile determined along the vector of the own actual velocity is known as

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the projectile lag.

It is important to bear in mind that the projectile lag and the curvature of the trajectory as projected on the plane of the velocities triangle is a relative ostensible phenomenon considered only in relation to the moving observer. It does not exist in the absolute system of coordinates. It goes without saying, that this apparent deflection depends primarily on the direction of the fire as related to the aircraft, i.e. on the angle of the hull gun.

The projectile lag can be calculated with an adequate degree of accuracy for practical application according to the formula

$$\boxed{z = V_1 D\left(\frac{1}{v_{cp}} - \frac{1}{v_{o1}}\right)}.$$

Let us examine now what changes would occur in the trajectory elements and in the sighting elements of the projectile if we considered the trajectory in relation to the gunner.

It is easily established that the relative and the absolute fall of the projectile are equal for, regardless of how we may see the movement of the projectile, the same interval of time passes in both cases from the moment the projectile is released and until it hits the target. Consequently, it will fall at the same distance whether seen by a stationary observer or by a moving gunner.

We know already that the distance from the point of release to the relative point of impact is not analogous to that of the absolute point of impact and may exceed the distance or be smaller depending on the direction of the relative velocity of sight.

Since the relative and the absolute distance of firing are not identical, the relative and the absolute angles of sight also differ. If the relative distance of firing were less than the absolute distance, the relative angle of sight would exceed that of the absolute one and vice versa, if the relative distance were greater the angle of sight would be smaller.

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92. General Scheme of Firing with Account of Relative Velocity of Target

We shall see now how the vector of absolute initial velocity v_o has to be orientated to hit the target taking its relative velocity into account.

Let us assume that the target that is at point A_o at the moment of release moves with velocity v_u toward the opposite intersecting course (see Fig.182). In order to hit this target the vector of relative initial ~~velocity must be~~ oriented so as to achieve that the trajectory of the projectile would pass through the relative point of impact. If the vector of relative velocity of the projectile were oriented directly toward the relative point of impact, the trajectory of the projectile would not pass through it, since the projectile would lag from the relative line of deflection by z. That means that the vector of relative initial velocity must be directed toward the point located at distance z from the relative point of impact in the direction of the path of the gunner's aircraft. But the trajectory would not pass through point A_y^1 either, but would be lower since the projectile falls under the effect of gravity. For that reason, the vector of relative initial velocity must not be oriented toward point A but higher by the value of the falling of projectile s.

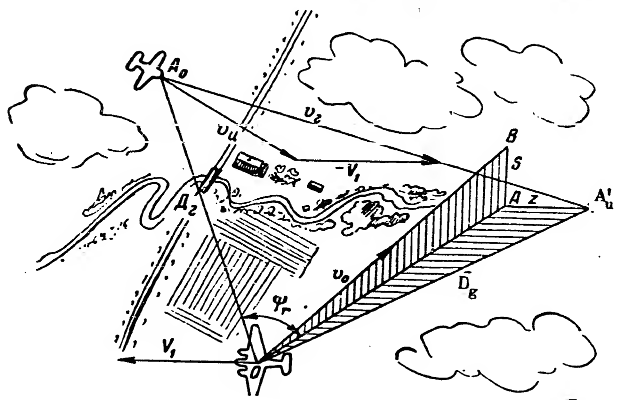

Fig. 182 General diagram of sighting with account of relative velocity.

Thus, the task of sighting [illegible] account of the relative velocity of the target is solved by the **formation** of three triangles: the relative triangle of lead $OA_{y}A^{1}_{y}$, the triangle of laying OAA^{1}_{y}, and the relative ballistic triangle OBA.

In this case the sight becomes stationary attached to the gun and an angle is formed between the sight axis and the bore axis that equals the angle of sight — in the vertical plane, and and angle that equals the angle of lagging — in the horizontal plane.

Let us examine now the methods of actual sighting with the gunner taking the relative velocity of target into account.

Chapter III

METHODS OF SIGHTING WITH ACCOUNT OF THE RELATIVE TARGET VELOCITY

93. Method of Sighting with Account of the Lateral Target Velocity

In order to compute the relative angle of lead we use the following formula:

$$\psi_2^r = 1000 \frac{v_n}{v_{cp}} .$$

This formula is much simpler than formulas used to compute the absolute angle of lead. In addition, it lends itself to the application in practical sighting. In fact, the mean velocity of the projectile in flight can be computed for average firing conditions. Let us assume that the lateral target velocity amounts to 100 kilometers per hour; we can proceed with the calculation of the relative angle of lead for this particular velocity by using a sight that has a ring with a radius, the angle of which would equal the relative angle of lead to be scaled.

If the lateral target velocity equaled the one that we have estimated (for instance, 100 kilometers per hour) the target must be placed on the ring. If the lateral target velocity were either greater or smaller than the one we have estimated, the distance of the target from the center of the ring must either be decreased or increased by as many times as the actual lateral velocity is smaller or greater than the one estimated by us. The apparent movement of the target must be directed toward the center of the ring. This movement can be carried out either sidewise or with the tail forward. Sometimes the nose of the enemy aircraft may be directed toward the center of the ring.

The gunner's task is confined to determining the lateral target velocity by the eye. But the whole complex task of sighting consists in the determination of the

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lateral target velocity. The essential difficulty of this task consists in the fact that various targets with identical lateral velocities but at different distances from the gunner travel at different angular velocities; however, we are used to judge the velocity of a body in motion by its angular velocity.

When flying at low altitudes we notice that we travel faster since the angular movement of the surface objects is great. However, at high altitudes and at a similar speed it appears that we are moving only slowly since the angular velocity of the surface objects is very small.

Another difficulty in determining the lateral target velocity is the lack of an auxiliary scale. In determining the foreshortening of the target the gunner uses the full length of the target fuselage or the relation between the apparent length of the fuselage and the apparent size of the range. The established angular dimensions of the target at various distances serve as a scale in determining the target distance. The absolute target velocity is determined according to the type of the aircraft. However, there is no scale to determine the lateral target velocity.

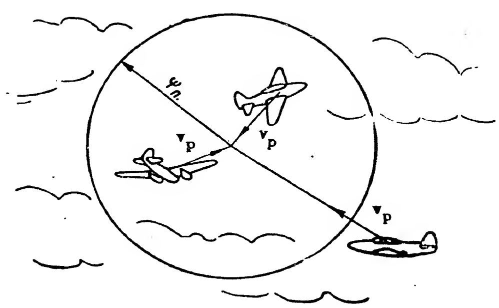

Fig.183 Sighting with account of lateral target velocity.

Only a thorough training provides the knowledge of determining the lateral target velocity.

Despite the difficulties experienced in determining the lateral target velocity this method of sighting is, nevertheless, simpler than any of the sighting methods based on the figuring of the absolute velocity. The gunner merely has to establish the lateral target velocity while he has to determine always the following two

factors with methods based on the absolute target velocity: in cases of fuselage sighting — the velocity and distance of the target and, with angular method — the target velocity and its foreshortening.

This is the most widely used sighting method with mobile gun installations. Let us examine now a few special cases of sighting with account of the relative target velocity.

94. Firing from Fighter at Aerial Targets

As already noted, the basic difference between methods of firing from a pursuit ~~plane and firing from mobile gun installations is the stationary installation of the~~ gun in a pursuit plane relative the gunner while sighting is carried out by the whole aircraft. The angle of the hull gun always equals zero and in sighting the aircraft always flies toward the set forward points if the dimensions of the sight angle were overlooked. For that reason, with the target angle at 90 degrees the lateral target velocity would equal its absolute velocity. At different target angles it would equal the projection of the absolute velocity on the direction that is perpendicular to the line of sight. Consequently in firing from a pursuit plane

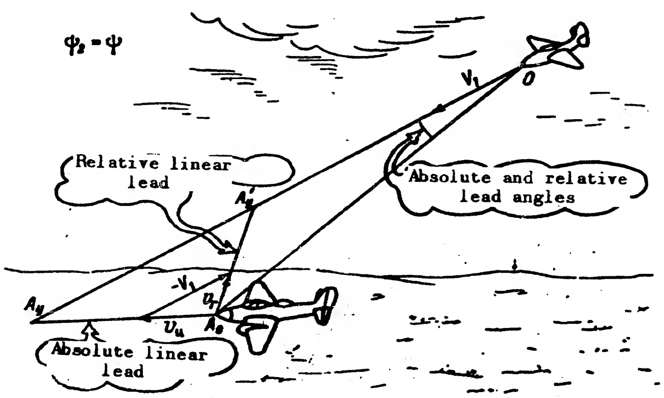

Fig.184 When firing from pursuit plane, the relative and absolute lead angles are equal: relative and absolute set forward points A_u' and A_u are situated on the same right line.

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As already noted, the basic difference between methods of firing from a pursuit plane and firing from mobile gun installations is the stationary installation of the gun in a pursuit plane relative the gunner while sighting is carried out by the whole aircraft. The angle of the hull gun always equals zero and in sighting the aircraft always flies toward the set forward points if the dimensions of the sight angle were overlooked. For that reason, with the target angle at 90 degrees the lateral target velocity would equal its absolute velocity. At different target angles it would equal the projection of the absolute velocity on the direction that is perpendicular to the line of sight. Consequently in firing from a pursuit plane

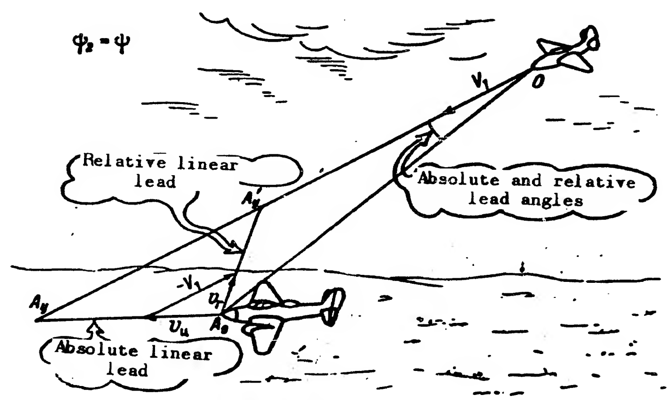

Fig.184 When firing from pursuit plane, the relative and absolute lead angles are equal: relative and absolute set forward points A_u' and A_u are situated on the same right line.

the lateral target velocity equals the product of its absolute velocity by the sine of the target angle, i.e. the foreshortening:

$$v_n = v_u \sin q.$$

Introducing this value to the formula of the relative angle of lead we would obtain:

$$\psi_r^T = 1000 \frac{v_u \sin q}{v_{cp}}.$$

If we compared this formula to that of the absolute angle of lead we would arrive at the conclusion that the relative angle of lead equals the absolute angle of lead in firing from pursuit planes:

$$\psi_1 = \psi.$$

Therefore, firing from pursuit planes can either be done with the usual methods, i.e. the fuselage or angular method, or with a method that would allow for the relative target velocity. In the latter case, member $v_u \sin q$ is not determined individually by the pilot, but together with the lateral target velocity.

95. Repelling Pursuit Plane Attack

Two essential conditions must be remembered when repelling an attack by a pursuit plane: first, firing in day light or under conditions of a clear night, and, second, firing under conditions of a dark night.

When firing in day light or under conditions of a clear night, the attacking pursuit plane moves toward the set forward point of the bomber that is ahead of it at a distance equal to the linear lead.

At night, a pursuit plane is unable to sight at any lead since the bomber fuselage is invisible. It, therefore, has to move toward some visible point (flame from exhaust pipes, light reflections, etc.).

Let us examine some of such cases.

a) Repelling Pursuit Plane Attack in Daylight and during a Clear Night

A pursuit plane attacked by a bomber moves towards its set forward point A_v^6

which is ahead of him at a distance $OA_y^6 = V_1 t$ (Fig.185). The gunner in the bombarder sees the pursuit plane along line OA_o. In order to hit the target the bombarder gunner must direct the vector of initial relative projectile velocity v_o so as to have the relative trajectory pass through the target that during the flight of the projectile would be relative point of impact A_y^i. For that purpose the sight axis together with the gun barrel have to be deflected from the initial target line by angle ψ_r. Let us find the dimensions of this angle for our case.

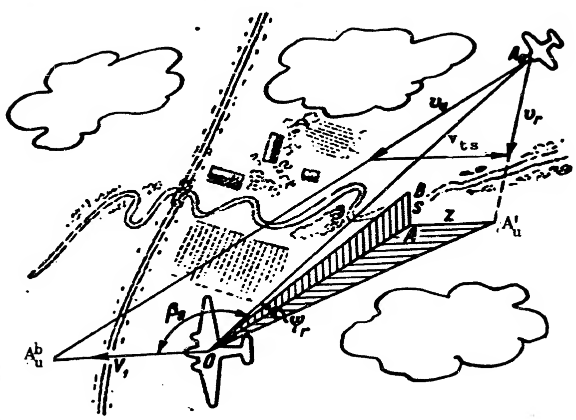

Fig.185 Sighting from bomber when repelling fighter attack in daylight or clear night conditions.

To determine the position of the relative set forward point we have to establish the dimensions and direction of the vector of initial relative velocity v_r. Therefore, we add geometrically vector V_1 to the end of the vector of target velocity v_u. The relative point of impact would be located on the continuation of vector v_r at distance $A_oA_y^i = v_r t$ from the target.

To have the trajectory pass through this point the vector of its relative initial velocity must be oriented toward point A located on the line parallel to the course of the own aircraft and at a distance from point A_y^i equal to the linear value of lagging z. Moreover, vector v_o must be raised by the angle of sight to make allowance for the fall of projectile s. Since the fall of the projectile is taken into account in boresighting the sight axis must be directed toward point A.

In this particular case the relative angle of lead under consideration of the projectile lag may be computed according to the formula

$$\psi_r^T = 1000\,\frac{V_1}{v_{o1}}\left[1 - \frac{v_u v_{o1}}{v_{cp}^2}\right]\sin\beta_o .$$

(In view of the complexity of this formula we quote it in its final form).

In the above form the formula is unsuitable for practical use; the gunner would be unable to compute the angle of lead. As a rule, the formula is greatly simplified and some omissions introduced.

The basic value that greatly affects the angle of lead is the relative angle of hull gun β_o. In fact, a change of angle β_o from 0^o to 90^o results in a change of the sine of this angle ranging from 0 to 1 while the relative angle of lead changes from 0 to its peak value, i.e. simultaneously with a change of angle β_o the angle of lead changes by many times.

Other values change within narrow limits and can be used with account of their mean value.

Thus member $1000\,\frac{V_1}{v_{o1}}\left[1 - \frac{v_u v_{o1}}{v_{cp}^2}\right]$ can be computed in advance.

As a rule, the following values are used for this member: V_1 stands for the peak value of the actual speed of the gunner's aircraft; v_{o1} represents installations with a ring-type sight and is considered equal to relative initial velocity $v_{o1}=v_o$; $v_{o1}=v_o+V_1$ stands for installations with forward fire and a minor deflection from the aircraft axis and $v_{o1}=v_o-V_1$ for installations with backward fire; target velocity v_u is always assumed to be the maximum velocity for the given type of target; the mean velocity of the projectile in flight v_{cp} is based on average firing conditions: $H = 4{,}000$ meters, $D = 400$ meters and the ballistic efficiency factor of the projectile released from the aircraft.

After computation of the above member we receive a certain constant number which the gunner must remember and in sighing multiply it by the sine of the relative inclined angle of the hull gun; this operation is also too complicated for a gunner.

For the sake of simplifying the task of computing the relative angle of lead further, the same technique is used here as in the establishment of the sine of the target angle, i.e. the foreshortening factor is introduced. The foreshortening can be determined with an accuracy of 1/4 but in this case it is more practical to calculate directly $\sin\beta_o$ with an accuracy of 1/3.

If multiplicator 3 were placed before member $\sin\beta_o$, i.e. $3\sin\beta_o$, the nominator and coefficient 3 would always be reduced when $\sin\beta_o$ is calculated with an accuracy of 1/3 while member $\sin\beta_o$ will be expressed by any whole number -- 0, 1, 2, and 3.

However, by placing coefficient 3 before $\sin\beta_o$ another multiplicator of the formula must be divided by 3 so that the equality is preserved. Consequently, the formula of the lead angle would look as follows:

$$\psi_r^T = \frac{1000}{3} \cdot \frac{V_1}{v_{ol}} \left(1 - \frac{v_u v_{ol}}{v_{cp}^2}\right) 3 \sin\beta_o.$$

Denoting $\frac{1000}{3} \frac{V_1}{v_{ol}} \left(1 - \frac{v_u v_{ol}}{v_{cp}^2}\right) = \psi_o.$

we obtain

$$\psi_r = \psi_o \, 3 \sin\beta_o.$$

Proceeding to compute $\sin\beta_o$ with an accuracy of 1/3 we obtain the following four basic values referring to the relative angle of lead:

With $\sin\beta_o = 0/3 \quad \psi_r = \psi_o 0 = 0$

" " $\beta_o = 1/3 \quad \psi_r = \psi_o 1 = \psi_o$

" " $\beta_o = 2/3 \quad \psi_r = \psi_o 2 = 2\psi_o$

" " $\beta_o = 3/3 \quad \psi_r = \psi_o 3 = 3\psi_o$

We see that in order to calculate the angle of lead the constant number ψ_o has to be first multiplied by one of the whole number 0, 1, 2 and 3, i.e. by the numerator of the fractional value of $\sin\beta_o$.

Denoting the numerator of the fractional value of $\sin\beta_o$, i.e. the numbers 0, 1, 2, 3 by N we obtain the following general formula:

$$\boxed{\psi_r^T = \quad {}_o N}$$

How can N or $\sin\beta_o$ be determined with the accuracy 1/3?

For that purpose the range of the changes of the angles β_o is divided in 4 intervals so that the mean values $\sin\beta_o$ in these intervals would be a multiple of 1/3.

We assume that

in intervals from 0° to 10° }
from 170° to 180° } $\sin\beta_o = \frac{0}{3} = 0$;
from 10° to 30° }
from 150° to 170° } $\sin\beta_o = \frac{1}{3}$;
from 30° to 60° }
from 120° to 150° } $\sin\beta_o = \frac{2}{3}$;
from 60° to 120° $\sin\beta_o = \frac{3}{3} = 1$.

It follows that if the target were in the front semisphere and the gun is deflected from the aircraft axis in any direction not exceeding 10° while sighting both N and ψ_2 would equal 0.

If the deflection angle of the gun ranges from 10° to 30° N would equal 1 and ψ_r would equal ψ_o etc.

The same reasoning applies to the rear semisphere. Since the gun can be turned in any direction from the aircraft axis the maximum deflection of the gun would be limited by conic planes with vertex $10\cdot 2 = 20^\circ$, $30\cdot 3 = 60^\circ$ and $60\cdot 2 = 120^\circ$. Between these planes so-called zones for certain values of $\sin\beta$ and N are formed.

Let us refer to the zone in the spread of 20° as No.0; to the zone in the spread of 60° as No.1, to the zone in the spread of 120° as No.2 and the rest as No.3.

On the basis of preceding reasoning it follows that number N would represent in the formula the zone number since within zone No.0 N equals zero, within zone No.1 N equals one, etc.

Consequently, in order to find the relative angle of lead when firing at an

an attacking pursuit plane the coefficient ψ_0 must be multiplied by the zone number in which the attacking pursuit plane moves.

The following rule of sighting can be established for the above case:

1. Discovering an enemy pursuit plane the gunner must determine the zone number of the enemy aircraft, multiply the coefficient ψ_0 that he must remember by the zone number and establish the relative lead angle.

2. Using rings or a ring-type sight as a measure he places the target at an angular distance from the ring center that equals the established angle of lead orienting at the same time the visible target shift toward the center of the ring and opens fire.

In general sighting as well as in the particular case examined here the visible motion of the target aircraft is directed toward the center of the ring instead of the lateral aircraft axis. In our case the target shifts toward the center of the ring sidewise.

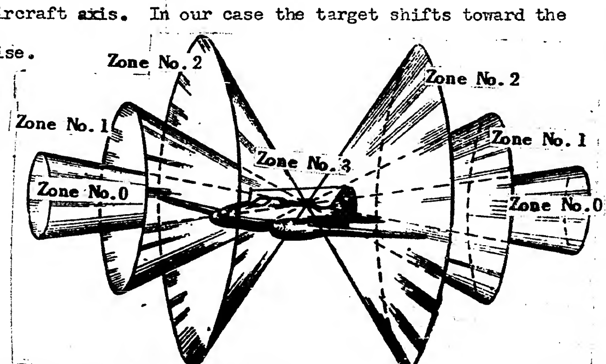

Fig. 186. Sight zones of bomber when repelling fighter attack.

Let us examine another case of aiming at an attacking pursuit plane.

b) Repelling fighter attack under dark night conditions.

When a fighter attacks a bomber at a dark night the sighting is done directly at a visible part of the bomber and the movement is directed toward this element. The target angle then equals zero; therefore, its foreshortening also equals zero

(Fig. 187).

In this case the formula of the relative angle of lead is greatly simplified expressed as follows:

$$\psi_r^T = 1000 \frac{V_1}{V_0} \sin \beta_0 .$$

Introducing once more coefficient 3 we obtain $\psi_r^T = \frac{1000}{3} \frac{V_1}{V_0} 3 \sin \beta_0$ or denoting

$$\frac{1000}{3} \frac{V_1}{V_0} \text{ by } \psi_{ou} \text{ and } 3 \sin \beta_0 \text{ by } N$$

we obtain finally

$$\boxed{\psi_r^T = \psi_{ou} N} .$$

In this case, too, the constant coefficient ψ_{ou} must be multiplied by the zone number of the attacking fighter in order to compute the relative angle of lead. In the process of calculation the zone numbers remain while the value of coefficient ψ_{ou} will no longer equal ψ_o. The gunner must also remember this number.

The rules of sighting are the same in this case as in the former.

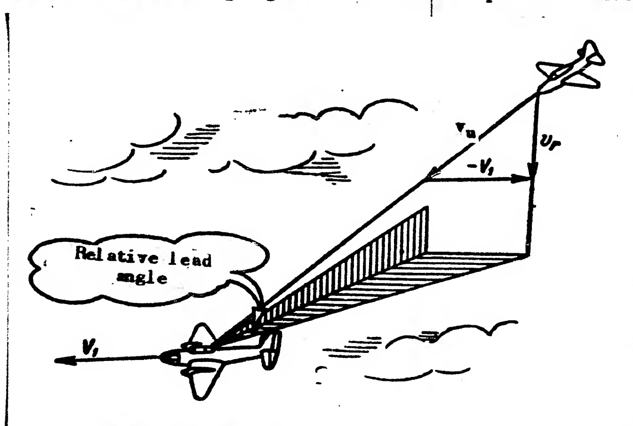

Fig. 187 Sighting from bomber when repelling fighter attack under dark night conditions.

96. Sighting when firing on parallel courses of the same and opposite direction

Let us assume that at the moment of firing the target is at point A_0 while the gunner is at point G (Fig.188). The vector of relative target velocity v_r

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must be established so that the relative angle of lead could be found. During the flight of the projectile the target would travel — relative the gunner — distance $A_oA'_y = v_r t$ and turn up in point A'_y. To hit the target the gunner must direct the gun at point A taking into account the projectile lag

$$z = A_yA.$$

In this case the relative angle of lead would equal

$$\psi_r = \frac{1000}{3} \left(\frac{v_u}{v_{cp}} - \frac{V_1}{v_{ol}} \right) 3 \sin\beta_o$$

or simplifying the formula as we have already done before:

$$\boxed{\psi_r^T = \psi_{o_u} N}$$

For some average conditions of sighting coefficient ψ_{o_u} must be calculated in advance. As in preceding cases number N represents the zone number in which the target is located.

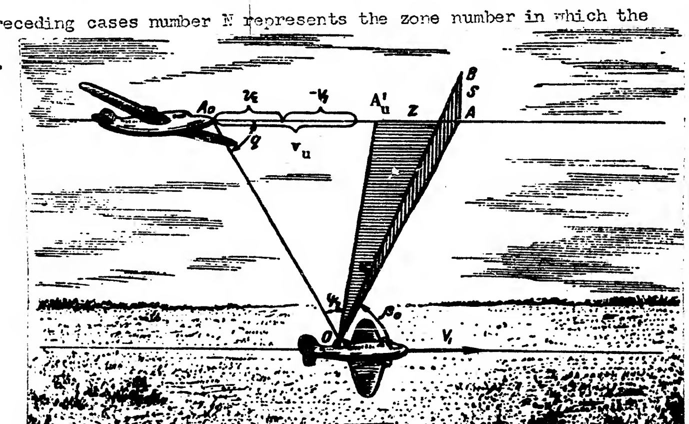

Fig. 188. Sighting when firing on parallel courses of same direction.

Sighting when firing on prallel courses of the same direction requires the study of the following three cases: 1) when $V_1 < v_u$, when $V_1 = v_u$ and when $V_1 > v_u$.

In the first case the relative target velocity is oriented in the same direction as the actual speed of the gunner's aircraft and in sighting the center of the ring

must be placed forward along the line of the target movement while the target axis must be directed toward the center of the ring. In the second case, the relative target velocity equals zero and in sighting the center of the ring must coincide with the target. In case $V_1 > v_u$ the target will lag, the relative target velocity will be directed against vector V_1 and in sighting the target must be placed within the field of the boresight so that its movements would be directed with the tail toward the center of the ring.

The formula for the angle of lead is represented as follows in firing on parallel courses of the opposite direction:

$$\psi_r^T = \psi_{ou}^N.$$

Despite the fact that the above formula does not appear to be very complex, firing on parallel courses of the opposite direction is rather ineffective since the high speeds of modern aircrafts result in such great relative angular shifts of the target that the gunner would have no time to sight properly.

97. General Rules of Sighting

Let us see now what the gunner would have to do to hit the target.

On a mission a gunner could not possibly prepare himself for special cases of firing since he may come across the target under the most unexpected circumstances. For that reason, he must know all ψ_o coefficients. He must also be familiar with the position and the outlines of the sighting zones.

It goes without saying that a knowledge of the three above-mentioned coefficients (we exclude the fourth coefficient for cases of firing on courses of the opposite direction) is inadequate since each of them applies to a specific target velocity. Since the velocity of aerial targets may very greatly a gunner must know the values of each coefficient for at least 2 - 3 groups of targets with a rather similar velocity. At present, we can classify fighters with propelling power and bombers into one group assuming that the velocity of aircrafts of this group equals

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600 kilometers per hour, while jet propelled fighters with a velocity of 850 to 1000 kilometers per hour belong to another group. Thus, for each individual case of firing two values of coefficient ψ_0 must be remembered and a total of six coefficients to cover all cases of firing.

In sighting the gunner must remember:

1. to size up the target and classify it in one of the above groups;

2. to establish the zone number and find the relative angle of lead by multiplying it by the appropriate coefficient;

3. to use the ring of the boresight as a measure in sighting and, directing the visible motion of the target toward the center of the ring, open fire.

98. What Method of Sighting Should Be Given Preference in Aerial Gunnery

We may now subdivide all methods of sighting into two groups: methods of sighting with account of the absolute target velocity, and methods of sighting with account of the relative target velocity.

In using all these methods sighting is done with the help of estimating by eye so that as far as accuracy is concerned both groups have an identical value. In both groups the gunner making allowance for the linear target velocity uses a measure estimating the necessary lead by eye and comparing it with the linear or angular scale available. In fuselage sighting, for instance, the target fuselage serves as a measurement and in sighting the necessary lead is figured out directly in terms of length of the fuselage target. In the angular method of sighting the length of the radii of the boresight rings serve as a measure. In sighting with allowance for relative target velocity the radius of the ring is also used as a measure.

Consequently, if a gunner masters the technique of figuring out exactly the necessary lead for all cases the errors in sighting would be more or less similar.

In addition to errors which the gunner may commit in sighting there are so-called methodical errors — a result of the range length on which one method or another is based. The fuselage method of sighting, for instance, is based on the

distance of the target in terms of hundreds of meters; i.e. that an "admissible" error, not to speak of the gunner's skill to estimate distance, would amount to 50 meters one way or another; a subdivision of targets into three groups only also entails certain errors since the actual target velocity may greatly differ from that established for a certain group into which we classify the given target.

In all angular methods errors occur in the calculation of the angle of lead at the expense of determining the foreshortening (with an accuracy of 1/4), the target velocity according to the aircraft type and the calculation of the mean projectile velocity under certain average firing conditions. Of the three angular methods of sighting examined here based on the absolute target velocity the calculation method is least vulnerable. The methods of conditional units allows for quite a few mistakes and the method of comparing velocities and foreshortenings for even more inaccuracies. Due to the averaging of the value of the mean projectile velocity inaccuracies may occur in the computation of the relative angle of lead. This method of sighting does not bring about other errors, that means that in comparison to other methods of sighting this method provides for the least methodical errors.

Finally, the gunner would inevitably commit errors when figuring out the necessary lead in determining the basic data for the estimate (range, target foreshortening, lateral velocity, etc.). From this viewpoint, the gunner is liable to commit the greatest errors in determining the lateral target velocity. For that reason, the advantages of the method with allowances for the relative target velocity are nullified by its disadvantages.

Thus, from the viewpoint of precise sighting, the methods based on both the relative and the absolute target velocity are, more or less, similiarly effective.

As far as the gunner's convenience is concerned the method based on allowing for the lateral target velocity may be preferable since it does not require any computation from the gunner; but the difficulty of determining the lateral target velocity brings this advantage to naught.

Consequently, from a viewpoint of the gunner's convenience none of thSTATove

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methods can be given preference.

The method of allowing for the relative target velocity has, however, an irrefutable advantage over other methods when it comes to the construction of automatic sights. We shall discuss this advantage below.

Chapter IV

PRINCIPLES OF AUTOMATIC GUN-SIGHTS IN FIGHTERS

99. Problem of Sighting Automatically at Targets in Motion

In examining the methods of sighting based on the principle of accounting for the absolute target velocity as well as the principle of accounting for its relative velocity we realize that depending on the method chosen the gunner must make certain calculations and estimates by eye in regard to one component of sighting or another.

Using the fuselage method the gunner must know how to estimate by eye or with the help of a range grid the distance to the target; he has to know how to recognize the target and know the over-all sizes and velocities. Directly before sighting the gunner must make a simple calculation of linear lead in the target fuselages multiplying the constant coefficient, which he must know, by the range in 100 meters.

Sighting with the help of the angular methods the gunner must know how to recognize his targets, determine their foreshortenings, know the velocity of various types of targets and also compute the angle of lead.

With methods based on the relative target velocity the gunner also has to resort to calculations. He also must know how to classify the target, to which group it belongs, how to determine the zone in which the target is located and he must remember the coefficient ψ_0 for each group of targets and for certain firing conditions. Here, too, the relative angle of lead is found by computation -- the gunner has to multiply the corresponding coefficient by the number of the zone.

Only two methods of sighting do not require any calculations on the part of the gunner: the method of comparing foreshortenings or the ring method and the method allowing for the lateral target velocity.

The first of these methods is very elementary and is hardly ever used now, the second one is very complicated since it requires the skill of determining the lateral

target velocity.

A certain time -- and it is only a matter of seconds -- is necessary to evaluate the essential data and to compute them before the projectile is released. In view of modern aircraft speeds and the briefness of air battles even fractions of seconds affect the attacking and firing. Furthermore, all the above-mentioned methods of sighting refer only to barrage fire since firing under aerial battle conditions is subject to constant changes. In the angular method of firing the foreshortening of the target shifts, in the fuselage method it is the range, in firing with account of the relative target velocity it is either the lateral velocity or the zone number that changes. Regardless of whatever factor we chose for sighting, it will always change. That means that the gunner must constantly make allowances for changed conditions of firing.

Many learned theorists and engineers have been trying to find simpler methods of solving the practical aspects of aerial gunnery while constructors of aerial gun-sights have been working on a sight that would compute the necessary data automatically reducing the gunner's actions to a purely mechanical operation of the gun-sight, so that he would no longer have to determine the basic data of sighting and be completely freed of making any calculations. This task was solved by the creation of a number of sights that have become quite popular in our country and abroad. Evaluating some domestic and foreign types of sights we could definitely state that our makes are simpler in construction and easier to handle; they are also more reliable and precise in action although the general principles of construction of both are almost identical.

The task of an automatic gun-sight consists primarily in relieving the gunner of having to calculate and solving the task of delivering accompanying fire. The latter can only be solved if the sight were to make automatic corrections in regard to the factors of sighting under changed firing conditions.

The automatic formation of the angle of lead should not necessitate the introduction of

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any factors on the part of the gunner that have to be estimated by eye since there would be no point then in having an automatic gun-sight.

So far it has not been possible to build an automatic gun-sight with account of the absolute target velocity. At the present stage of the technological development of measuring devices, no device has been designed to establish the absolute target velocity from an aircraft in flight and the sight is mounted on a moving aircraft. For that reason, the task of forming the angle of lead automatically was resolved only with allowance of the relative target velocity.

We have two formulas to compute the relative angle of lead:

$$\psi_r^T = 1000 \frac{v_n}{v_{cp}} \quad \text{and} \quad \psi_r^T = 1000\,\omega_u t.$$

The first of these formulas can hardly be used in automatic sighting since the lateral target velocity incorporated in it can only be judged by eye. Speaking generally, it is extremely difficult to estimate linear values -- sizes and velocities of bodies that may be located at different ranges. We evaluate the velocity of a body according to the speed of its angular movement. From this point of view, the second formula is certainly very handy. For the automatic formation of the relative angle of lead determined by this formula a mechanism that would determine the angular target velocity is required, a mechanism that would compute the time of flight of the projectile under various firing conditions and a mechanism that would multiply these values forming the necessary angle of lead.

Dozens of devices are known in technology with the help of which any mathematical calculations can be carried out, so that this task is not very difficult.

How can the angular target velocity and the time of the flight of the projectile be determined individually?

If the gunner will keep his gun pointed at the target after combining the cross hairs with the target the sight axis, i.e. the sight, will turn with a certain angular velocity which will precisely equal the angular target motion. By attaching

a tachometer or a centrifugal pendulum, the angular velocity at which the sight-mechanism turns can be recorded at any moment, i.e. the angular target velocity.

The time of flight of the projectile can be established by measuring the range and adjusting the sight-mechanism accordingly. Other factors that affect the time of flight of the projectile can be estimated in accordance with their average value.

The range must be found mechanically, so as to relieve the gunner of any calculations.

With the modern high speeds of aerial targets the range has considerably increased; depending on the conditions of an air combat targets change greatly their path so that the gunsight alone no longer suffices to evaluate the fall of the projectile. Consequently, another problem arises in constructing automatic gun-sights -- the formation of the elevation. The angle of elevation is, primarily, affected by the range. However, the range has to be found in any case so that the angle of lead may be formed. Once the range is set it can be taken into account in forming the angle of elevation, so that the latter is always ready in accordance with the range.

We see that the automatic gun-sight has two tasks to solve: first, forming the relative angle of lead and, second, adjusting the angle of elevation to the given firing conditions. Let us see now how these tasks can be solved automatically in a gun-sight mounted on a pursuit plane.

To begin with, we shall make a small excursion into the field of mechanics and get acquainted with the features of a remarkable device known as the gyroscope. For a better understanding of the principles upon which automatic gun-sights are built it is necessary to have a knowledge of these features.

100. Excursion into the Field of Mechanics to Get Acquainted with the Properties of a Gyroscope

It was established over two centuries ago that bodies revolving at high speed

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acquire certain characteristics that differ from those of stationary bodies.

We are all familiar with an ordinary toy —the top— a wooden or metal disk mounted on an axis with a sharp end.

We shall inevitably fail if we tried to place a stationary top on the sharp end of the axis. But if we imparted motion to the top we shall be able to place it on the axis without any difficulties and it will not fall as long as it continues to revolve at a sufficiently high speed. We shall easily find out that the top would not even fall when its axis is greatly deflected from the vertical. Then, the axis of the top describes a circular movement which is arbitrary and without any ostensible reason near the vertical that passes through the point of rest.

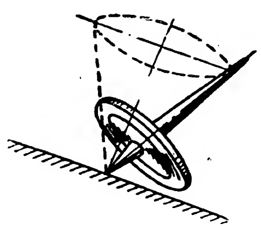

Fig.189 A top to which has been imparted a motion of rapid rotation does not fall; its axis merely describes a circle in space.

Who has not seen jugglers perform with plates or balls and we know that before placing a plate on the sharp end of a stick or holding up a ball with one finger or on the tip of the nose the performer would inevitably set them in motion.

Bodies revolving at high speed have the property of resisting any change in position.

In 1752, Serson suggested to use the characteristics of rapidly revolving bodies to form an "artificial horizon" on a boat. Unfortunately, the SS Victoria on board of which he had been testing his discovery was shipwrecked. The inventor perished and his invention was forgotten.

A hundred years had to pass before new attempts were launched to utilize the properties of a revolving body. These attempts originated with Foucault's famous experiments on which he reported before the Paris Academy of Sciences in the year 1852.

It was Foucault who introduced the term "gyroscope" to science. Literally,

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it defines "a device to view the rotation."

This definition is clearly understood if we pointed out that with the help of a rapidly revolving fly-wheel Foucault established the rotation of the earth about its own axis in a laboratory for the first time. In its present use "gyroscope" applies to any device with the characteristics of a rapidly revolving body. Forthwith we shall use the word "gyroscope" in this connection.

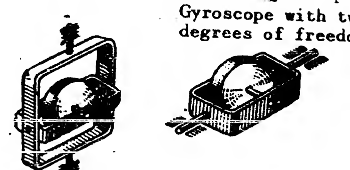

Fig. 190. Gyroscopes with varying numbers of degrees of freedom.

In the subsequent 50 years, however, the gyroscope was not used in practice since the state of technology at that period made any application of the device impossible.

The first gyroscopic compasses were constructed as late as in 1906. The rapid development of technology led to the invention of new precise gyroscopic instruments. Now, gyroscopic devices assume increasing importance in various branches of technology. In military technology gyroscopes are widely used, particularly, in aviation and navigation.

The basic part of a gyroscope is a disk fly-wheel or another revolving body imparted with an axis that rotates in space in one direction at least.

The basic characteristic of a gyroscope is its resistance to any change in position. If the revolving axis of a gyroscope were directed to a star in the sky, we could see that continues to "gaze" at this star as long as the latter moves together with the horizon. As soon as the star vanishes beyond the horizon, the axis of the gyroscope continues to follow it and will be directed directly toward the same star when it rises again at the opposite end of the horizon. Since the visible movement of the stars is caused by the rotation of the earth about its own axis, we know that the axis of the gyroscope does not rotate with the earth, but keeps its direction constant in space. A gyroscope provided with an axis that can

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turn in any direction will behave in this specific manner.

The reaction of a gyroscope to the forces that act upon its axis is completely different.

We know that the axis of a top revolving on a horizontal plane does not remain stable in its direction, but makes a circle and this conic revolution of the axis is not arbitrary but takes place in a certain direction, at a definite speed and with a definite angle of taper. The slower the rotation of the top, the greater the angle at the vertex of the cone.

If we changed the direction in which the top revolves, we would notice that the direction of the conical motion of its axis would also change. If we undertook to deviate the axis of a revolving top in any direction, we would find that it will never deflect in this particular direction but always continue to revolve in the direction that is perpendicular to that of the acting forces. After s series of tests with a top, the law of the deflection of its axis under the effect of a force is easily understood as follows:

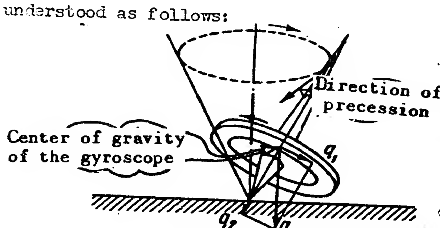

Fig. 192. The conical motion of the axis of a top may be seen as precession resulting from the pull of gravity.

If any force acted upon the axis of a top that is perpendicular to it, this end of the axis would deflect in the direction indicated by the vector of the velocity at which the top revolves, drawn through the end of the vector of the acting force.

Let us see how the conical motion of the axis of a top can be explained. The top is under the action of gravity that tries to pull it down. The greater the deflection of the axis from the vertical, the stronger the pulling force as the gravity, that is directed here perpendicularly to the axis of the top, will also in-

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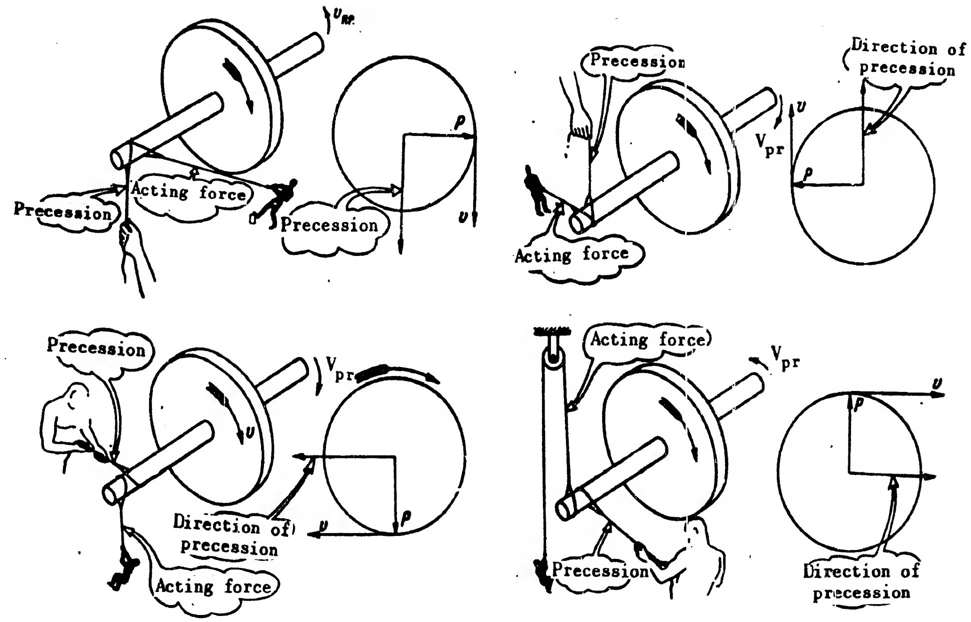

Fig. 191. The direction of precession is shown by the vector of the velocity of rotation of the gyroscope rotor; this vector is drawn through the end of the vector of the force acting on the axis of the gyroscope.

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crease. The action of this gravity brings about the deflection of the axis of the top in perpendicular direction and since this component is continuously active revolving with the axis, it is natural that the axis also deflects continuously trying to get away from the action of force. As soon as the revolution of the top slows down, its axis begins to rotate in an increasingly wider spread, until it tumbles on the surface on which it has been placed.

The motion of the axis of the gyroscope under the action of outside forces is called precession.

If the end of the axis of a top were placed on a point of support, so that it would be in horizontal position, it would not fall provided that its rotor would revolve rapidly continuing to rotate (precess) on the horizontal plane.

By having various forces act upon the axis of the gyroscope we may convince ourselves that the angular velocity of its revolution increases as the forces that act upon it increase. However, the greater the distance from the rotor and the less action there is, the greater the angular velocity of the rotor rotation; the rotor shows a higher resistance to any change in position and its spread in relation to the revolving axis increases accordingly. In other words, the angular precession velocity is directly proportional to the moment of the applied force and inversely proportional to the angular velocity of the motor rotation and the moment of inertia.

Without dwelling further on the properties of the gyroscope, we shall see now how these properties may be applied in order to form the angle of lead and the elevation.

101. Formation of the Relative Angle of Lead by the Sight-Mechanism of a Pursuit Plane

When it comes to the automatic formation of the relative angle of lead with the sight-mechanism of a mobile gun installation, the problem of estimating the angular target velocity presents no difficulty, since the angular velocity at which

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the sight-mechanism is turned may be judged according to the velocity of its turn in relation to the aircraft.

It is much more difficult to determine the angular target velocity with the help of an automatic sight-mechanism in a pursuit plane. The sight-mechanism in pursuit planes is stationary; therefore, the sight axis can only be adjusted by turning the entire aircraft. Consequently, it is necessary to know how to find the angular velocity at which the aircraft turns since the gun-sight does not shift in relation to the aircraft.

A device that would not turn together with the aircraft and could be used for the purpose of comparison is, therefore, needed to estimate the angular velocity at which the aircraft turns. Then, the angular velocity at which the aircraft turns could be determined by the relative angular turn of the aircraft and that of the device. It follows, that the angular target velocity could also be established.

For the above purpose only the gyroscope can be utilized since one of its axes always resists any changes of position in space.

If a gyroscope in an aircraft were imparted rapid motion, its axis would continue revolving all the time in the same direction regardless of any turns and moves of the aircraft. By measuring the velocity at which the angle between the aircraft axis and the axis of the gyroscope increases, it is possible to establish the angular velocity at which the aircraft turns and if the axis of the aircraft were constantly oriented toward the target, we would obtain the angular target velocity.

Let us see now how this angular target velocity helps to form the angle of lead.

For a better understanding of this operation, let us imagine that the gyroscope possesses the unusual properties (Fig. 193) that we try to impart to it.

While an aircraft is in rectilinear flight the axis of the gyroscope is parallel to that of the aircraft. When the pilot begins to turn the axis of the gyroscope in tracking, the axis maintains, to begin with, its original direction lagging

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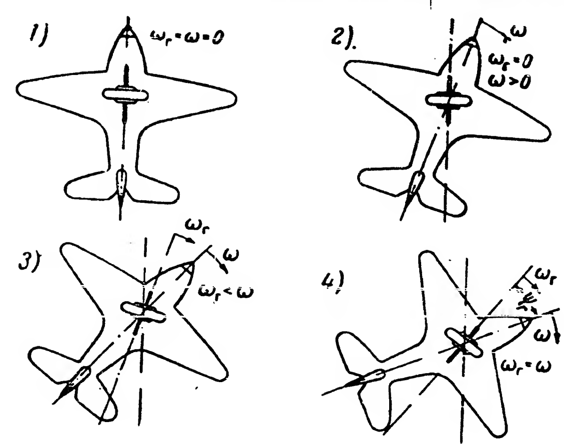
behind the axis of the aircraft by a certain angle; eventually, it begins to follow the axis of the aircraft but at a lower angular velocity, i.e. while no longer following its original direction it will, nevertheless, lag behind the axis of the aircraft.



We assume that the gyroscope is able to turn faster as the angle that has formed between the axis of the gyroscope increases. At a certain angle of divergence the velocity at which the gyroscope turns coincides with the velocity at which the aircraft turns. As the gyroscope continues to turn the angle between the axis of the aircraft and that of the gyroscope remains constant, provided that the angular velocity of the aircraft does not change. If this angle were greater, the angular velocity at which plane turns would also increase in proportion. In tracking operations it also increases in proportion to the angular tar-

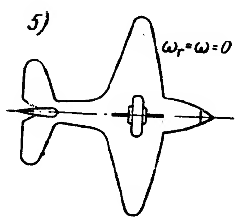


Fig.193 Let us imagine a gyroscope, characterized by the following unusual properties: (1) in rectilinear flight, the axis of the gyroscope coincides with that of the plane; (2) when the plane turns, the axis of the gyroscope, in its tendency to maintain its original position, begins by lagging behind the axis of the plane; (3) the axis of the gyroscope begins to follow the turn of the plane, but at a lower angular velocity; (4) at a given angle of lag ψ_r, the axis of the gyroscope begins to turn at the same velocity as the axis of the plane; (5) as the plane resumes its rectilinear flight, the axis of the gyroscope catches up with that of the plane, and from then on coincides with it.

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We assume that the gyroscope is able to turn faster as the angle that has formed between the axis of the gyroscope increases. At a certain angle of divergence the velocity at which the gyroscope turns coincides with the velocity at which the aircraft turns. As the gyroscope continues to turn the angle between the axis of the aircraft and that of the gyroscope remains constant, provided that the angular velocity of the aircraft does not change. If this angle were greater, the angular velocity at which plane turns would also increase in proportion. In tracking operations it also increases in proportion to the angular tar-

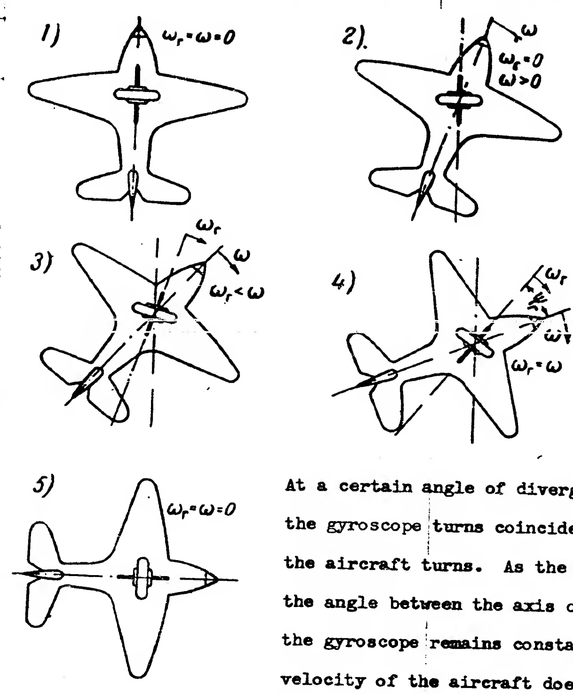

Fig.193 Let us imagine a gyroscope, characterized by the following unusual properties: (1) in rectilinear flight, the axis of the gyroscope coincides with that of the plane; (2) when the plane turns, the axis of the gyroscope, in its tendency to maintain its original position, begins by lagging behind the axis of the plane; (3) the axis of the gyroscope begins to follow the turn of the plane, but at a lower angular velocity; (4) at a given angle of lag ψ_r, the axis of the gyroscope begins to turn at the same velocity as the axis of the plane; (5) as the plane resumes its rectilinear flight, the axis of the gyroscope catches up with that of the plane, and from then on coincides with it.

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get velocity.

Let us go even further assuming that this angle would be directly proportional to the angular velocity at which the aircraft turns.

As the gyroscope is characterized by such remarkable properties, we may proceed with the formation of the angle of lead.

Here is how we go about it.

Let us assume that some kind of optical sight-mechanism is rigidly attached to the gyroscope. The axis of this optical sight-mechanism would run parallel to that of the gyroscope. To simplify our task, let us suppose that the line of the optical sight-mechanism coincides with the axis of the gyroscope.

We shall also assume that after identifying the target, the pilot makes the target line coincide with that that of the optical sight-mechanism by maneuvering his aircraft. In other words, he lines up the axis of the gyroscope and, trying to maintain the line of sighting steadily on the target he tracks it by turning his aircraft.

Since the pilot maneuvers his aircraft to track the target with the help of the axis of the gyroscope, the axis of the aircraft deflects from the axis of the gyroscope moving in front of it and preceding the target in the direction of its visible movement.

To begin with, the axis of the gyroscope would slide off the target either lagging or overtaking it. By manipulating his control wheels the pilot achieves that the axis of the gyroscope points steadily at the target.. This becomes possible when the angular velocity at which the axis of the gyroscope turns coincides with the relative angular target velocity.

If the angular velocity at which the aircraft turns were either greater or smaller than the angular target velocity, the target would either lag behind or overtake the axis of the aircraft, i.e. it would lag behind the axis of the aircraft and that of the gyroscope or catch up with them. However, if the angle between

the axis of the aircraft and that of the gyroscope were decreased, the angular velocity at which the gyroscope axis turns would also increase and — at a given moment — the angular velocity of both would be alined. If the axis of the gyroscope lagged behind the axis of the aircraft, the increase of the angle between the axes would result in increased angular velocity of the axis of the gyroscope [illegible] alinement with the angular velocity of the aircraft. It follows, that after the axis of the gyroscope is fixed on the target both, the gyroscope and the aircraft, turn at an angular velocity that equals the angular velocity of the target forming an angle between the axis of the aircraft and that of the gyroscope.

Should the relative motion of the target change, its angular velocity would either increase or diminish so that the angular velocity at which the aircraft turns must also be increased or diminished in proportion in order to maintain the axis of the gyroscope in its original position. Once this velocity is diminished, the axis of the gyroscope approaches the axis of the aircraft and turns, eventually, at lower speed; if the aircraft turned at an increased velocity, the axis of the gyroscope would deviate from that of the aircraft also turning at higher speed. In the former case, the angle between the axis of the gyroscope and the axis of the airplane would diminish, in the latter it would increase. Consequently, this angle will increase as the angular target velocity increases and diminish at lower velocities. The axis of the aircraft and, consequently, the axes of the gun-barrels which are mounted stationary in the aircraft, precede the motion of the axis of the gyroscope which the pilot brings in line with the target. That means, that the guns are adjusted following the visible target movement. If the axis of the gyroscope lagged behind the axis of the aircraft by an angle proportional to the angular target velocity, it would follow that the angle between the axis of the gunner's aircraft and the axis of the gyroscope would be proportional to the relative angle of lead. This angle would exactly equal the necessary angle of lead for a certain range of firing. If it were to be applied to other ranges it would have to be diminished or increased

according to a decreased or increased time of flight of the projectile and by the respective range.

Consequently, a device must be used to increase or decrease the angle that forms between the axis of the aircraft and the axis of the gyroscope in accordance with a given range or firing. We know, that the angle of lead is not greatly affected by change in range, but we also know that the angular velocity of the target changes greatly with the range and is inversely proportional to it. Since the angle of lead has to be increased in firing at a remote target and we know that in our sight-mechanism it is automatically decreased as the angular target velocity decreases, a device must be applied that would take this factor into account. Two adjustments would have to be made by this range corrector: adjustments according to the changed time of flight of the projectile, and adjustments necessary in view of the changed angular target velocity. This is required to prevent that the angle

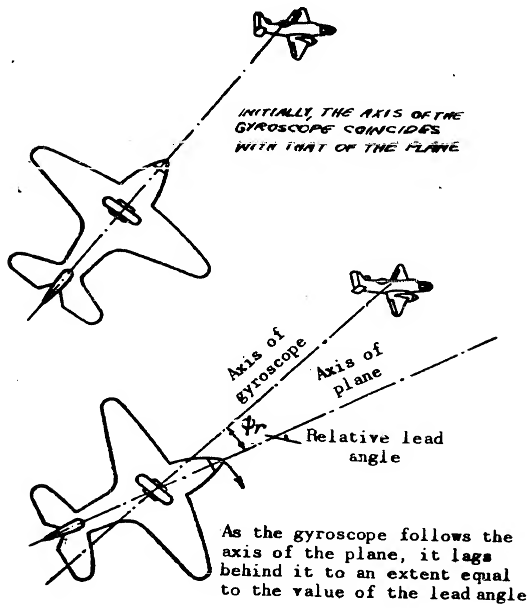

Fig. 194 In the process of tracking the target the sighting mechanism forms the relative angle of lead.

decreases as the range diminishes. In other words, a position must be achieved at which the angle between the axis of the aircraft and the axis of the gyroscope would always equal the necessary angle of lead that corresponds to a given range while the target is tracked.

Under these circumstances, maintaining the line of the sight on the target the pilot can open a steady accompanying fire since any change in firing conditions, i.e. any changes in the angular target velocity or in its range, are automatically and continuously registered and corrections made in the angle of lag of the axis of the gyroscope and that of the aircraft.

So far no gyroscope has been available with these properties. We shall certainly work on its construction. We are aware of the fact, that one of the most outstanding properties of a gyroscope is the ability of its axis not to deviate in the direction of the acting force under the effect of this force upon the axis — under the condition, of course, that the gyroscope revolves at an adequately high speed — but to deflect always in the direction that is perpendicular to the direction of the acting forces.

This characteristic of the gyroscope may be utilized for the formation of a relative angle of lead.

We must make the gyroscope precess with an angular velocity equal to the angular velocity at which the aircraft turns and, consequently, to the angular velocity of the target. However, we have to make sure first that the axis of the gyroscope lags behind the axis of the aircraft by an angle that equals the relative angle of lead.

For reasons of efficiency we shall divide this task and begin with the question of how to make the axis of the gyroscope follow the axis of the aircraft. Then we shall proceed to examine how we can make it rotate with an angular velocity that would equal the angular velocity of the aircraft. Our final task would be to achieve that the axis of the gyroscope lag behind the axis of the aircraft by an angle equal to the necessary angle of lead.

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To make the axis of the gyroscope turn in a certain direction, the force perpendicular to this direction and oriented accordingly must be applied to its axis. If, for instance, the gyroscope rotor turned clockwise (looking along its axis from tail to nose) while the aircraft turns to the right, we would apply downward force following the law on the direction of the precession toward the rear end of the axis of the gyroscope. When the aircraft turns to the left upward force would be applied, when it climbs, this force must be directed to the right; when the aircraft turns downward the force is directed to the left. Thus, the axis of the gyroscope will always follow the axis of the aircraft. These forces must, however, only be acting while the aircraft turns. They must be increased as the angular velocity of the aircraft also increases and the axis of the gyroscope adjusted in a parallel position relative to the axis of the aircraft. When the aircraft ceases to turn the action of these forces must also stop and no longer act when the aircraft proceeds in rectiangular flight.

To solve this task we shall have to resort to electrical engineering.

Let us attach a non-magnetic metal disk to the end of the rotor axis and let us balance it by a corresponding shift of the rotor along the axis of rotation.

We shall then set up the gyroscope in an aircraft so that the rotor axis would run parallel to the aircraft axis while the disk would be on the side of the tail. Opposite the center of the disk a stationary magnetic pole would be attached. As the gyroscope is set in motion, the disk attached to the axis would rotate in the magnetic field of the magnet. We know that in similar cases induction currents or so-called Foucault currents are produced in metal disks. According to the Lenz's law direct induction currents are always produced to inhibit the motion by which they are produced due to their magnetic action. Consequently, if the magnetic pole were placed opposite the center of the disk, the magnetic action of the currents produced in the disk as the gyroscope rotor revolves, would have a braking effect on the rotor motion. This braking effect will be overcome by the motor that sets

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the rotor into action with the result that the gyroscope would not turn. Let us assume that the aircraft is making a left turn. Since the gyroscope maintains the direction of its axis in space, the aircraft shifts the magnet from its position opposite the center of the gyroscope disk to the right by turning. The Foucault currents produced in the disk opposite the magnetic pole will follow a direction in which their action resists the direction of the peripheral speed of the disk near the center of the magnetic pole, i.e. the braking effect on the disk would be directed upward as the rotor revolves to the right. Since the force is directed upward while the vector of the peripheral velocity of the disk conducted through the end of the vector force is directed to the right, the rear end of the rotor axis of the gyroscope would deflect to the right; consequently, the front of the rotor axis would deflect to the left following the axis of the aircraft. It is obvious that the greater the angular velocity at which the aircraft turns, the greater the angle at which the axis of the gyroscope lags behind the axis of the aircraft, and the greater the shift of the magnet in relation to the center of the disk. Since the linear velocity at which the metal disk passes the megnetic pole increases the farther the magnet moves away from the center of the disk, the braking effect on the disk will also increase as the magnet shifts. That means, that at great angular velocities the angle of lag of the gyroscope axis will increase in proportion with the increase in the shift of the magnet away from the center of the disk. The forces that act on the disk will also increase and, consequently, the gyroscope will precess with greater angular velocity. At lower angular velocity, the axis of the gyroscope will catch up with the axis of the aircraft under the braking effect, the shift of the magnet relative to the disk will diminish producing a stronger braking effect and a decrease in the angular velocity of the rotor axis. This will continue until the angular velocities of the gyroscope and of the aircraft are adjusted. As soon as the aircraft ceases to turn, the axis of the gyroscope catches up with the axis of the aircraft under the braking effect, so that both coincide.

Thus, each angular velocity at which the aircraft turns has a certain corresponding angle at which the axis of the gyroscope lags behind the axis of the aircraft, regardless in which direction it turns.

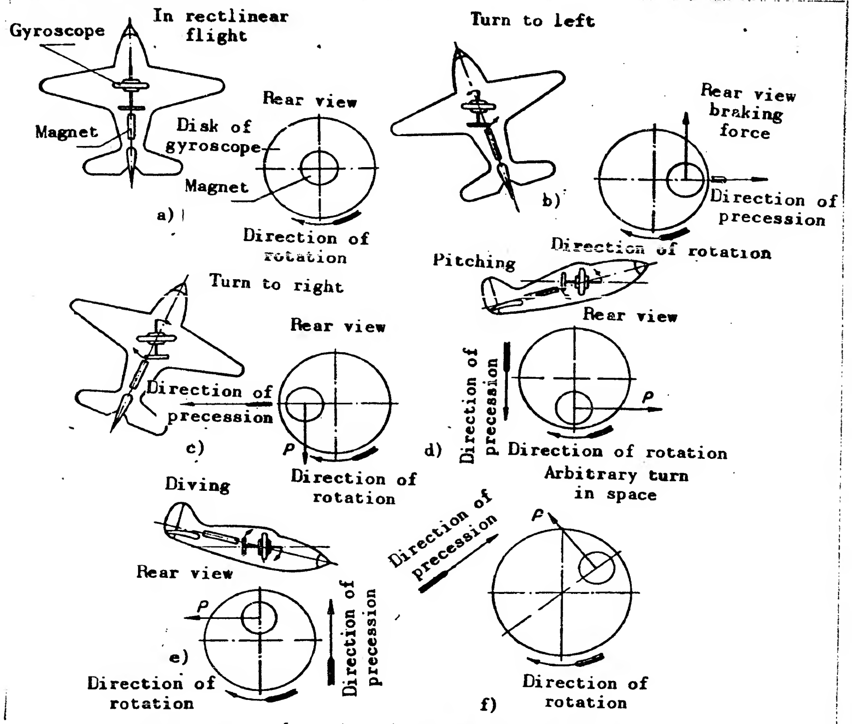

Fig. 195 By using a magnet, it is possible to make the axis of the gyroscope follow that of the aircraft.

By applying a magnet of a certain force, it could be made possible that each angular velocity at which the aircraft turns — i.e. each angular target velocity— would correspond to an predetermined angle that forms between the axis of the aircraft and that of the gyroscope. This angle, in turn, equals to the required angle

of lead that corresponds to a certain range.

Such correspondence would not exist in other ranges, since the angular target velocities will change as well as the time of flight of the projectile while the lateral velocity remains the same.

The required angle of lead must be determined so that the range can be set. For that purpose, the force that acts upon the axis of the gyroscope must be changed. However, this can only be accomplished by either changing the velocity at which the gyroscope revolves or the magnetic tension. By changing the velocity at which the gyroscope revolves the desired effect would not be produced because the disk fly-wheel of the gyroscope is characterized by great inertia so that any corrections of the angle of lead formed by the gyroscope would be made with great delay. Therefore, we have to resort to the second method: changing the value of the force by changing the magnetic field. By using an electromagnet instead of an ordinary magnet this is easily accomplished. A change in the strength of the current in the electromagnetic circuit would result in a change of the tension in the magnetic field. This change affects the value of the acting force that affects the axis of the gyroscope. The range may be fed in the sight-mechanism by regulating the slide of the rheostat that is connected to the electromagnetic circuit. Allowance must be made in the rheostat winding for the angle of lead formed by the gyroscope, so that it would correspond to the range setting in the sight-mechanism. This includes changes in the angular target velocity in conformity with a given range as well as the effect of a given range upon the angle of lead.

Thus, the problem of forming the angle of lead automatically can be solved.

In sighting, the pilot's task is confined to maneuvering his aircraft and maintaining the optical sight that is connected to the gyroscope axis on the target and adjusting continuously the range.

Below, we shall report on methods of range setting, but first we shall dwell on the task of forming the angle of sight.

102. Forming the Angle of Sight

For the formation and adjustment of the angle of sight in accordance with a given range, the same technique as used to form and adjust the angle of lead may be applied. Let us visualize another electromagnet placed above the main electro-

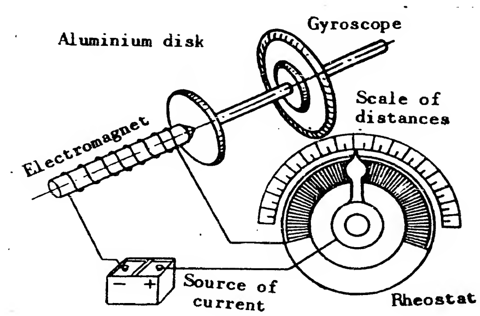

Fig. 196. The angle of lead made by the gyroscope may be made to depend on the range, provided that an electromagnet is used instead of an ordinary magnet.

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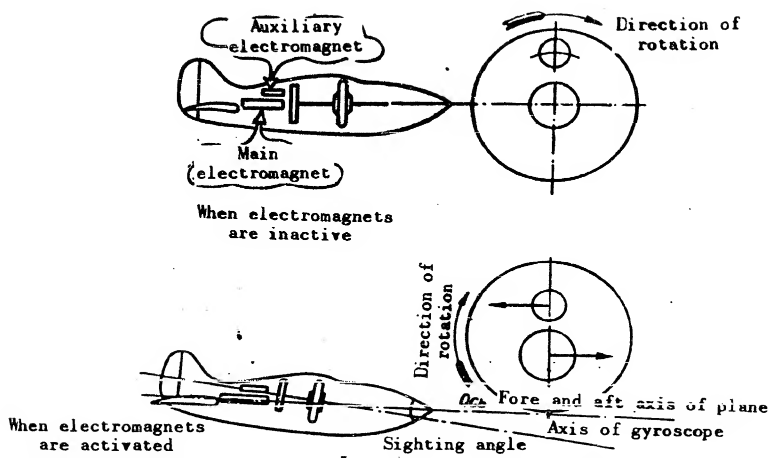

Fig. 197. This shows how the angle of sight is formed by means of an auxiliary electromagnet.

magnet located opposite the center of the gyroscope disk and serving to form the angle of lead. Under the action of Foucault currents the braking effect is directed against the rotor movement. If the rotation of the gyroscope were clockwise, this force would be directed to the left. With the help of the law of precession, it is easy to establish that the rear end of the rotor axis with the disk closest to the pilot would deflect upward. That means, that the front of the gyroscope axis would deflect toward the axis of the aircraft. By maneuvering the aircraft, the axis of the gyroscope can be alined with the target. In this case, the axis of the aircraft and, therefore, the axes of the gun-barrels mounted on the aircraft would be directed above the target. By changing the strength of the current in the electromagnetic circuit, the angle between the axis of the gyroscope and the axis of the aircraft could be made to equal exactly the angle of sight at a given range. By a further change of the strength of the current in the electromagnetic winding, the angle of sight can be adjusted for any range. It is, however, necessary to adjust the sight-mechanism to the changed range. The same applies to the rheostat slide that is connected to

the electromagnetic circuit. The rheostat winding would, of course, have to be adjusted accordingly.

Now, the only problem left is the finding and setting of the range.

103. Range Setting with the Help of a Sight-Mechanism

There are two ways to find the accurate range. Both are based on scaling the angles of a given base that can be chosen either by reference to the gunner's aircraft or by reference to the target. Depending on the site of this base, the methods of finding the range are known as 1)method to determine the range in reference to the gunner's plane, and 2) method to determine the range in reference to the target.

In the first case, the range is found by scaling angles α and β and solving the two angles of triangle AA_0C and side (base) $AC=B$. However, this method is not used in aerial gunnery since it would be too much to expect the gunner to determine angles α, β (Fig.198).

In the second case, a given target length serves as the base such as, for instance, the length of the fuselage or the length of the span (Fig.199). After determining the angle at which the base is visible, we may find the range with the

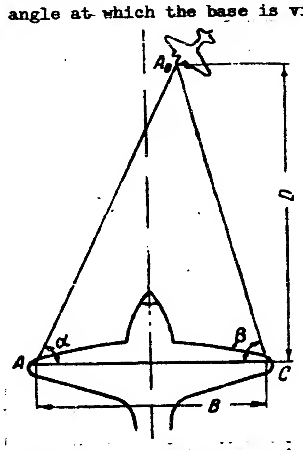

Fig. 198 Principle of finding range by reference to the plane of the gunner.

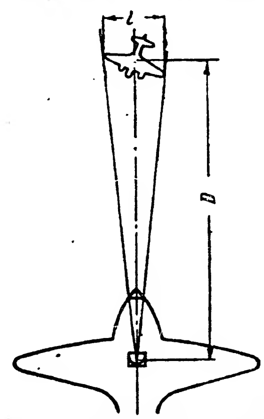

Fig. 199 Principle of finding range by reference to the target.

help of the following formula that has already been quoted:

$$\boxed{D = 1000 \frac{l}{\gamma} T}$$.

Since a target aircraft may be at various foreshortenings, and sometimes the span is visible, sometimes the length of the fuselage and sometimes both, the distance between the most remote points of the visible silhouette of the target is considered as the base. This length is considered equal to the mean arithmetic value of the length of the span and that of the fuselage, i.e. half the sum of the length of the span and the fuselage.

This principle is the basis for finding the range with a range finder in automatic sight-mechanisms. The gunner does not have to find the range by calculation but merely has to set it automatically with the help of the sight-mechanism.

When using a ring-type sight-mechanism, the gunner estimates the target angles by the eye through a range grid in the sight-mechanism. If automatic range finders were also constructed along this principle, the gunner would not only have to scale the target angles and estimate the range, but would have to set it while sighting, so as to form the angle of lead and the angle of sighting. However, the idea is to relieve the gunner of this operation and to have an automatic range finder.

Let us imagine that in the field of vision of the sight-mechanism there are two pivots which the gunner may either draw together or pull apart with a mechanical device. The gunner would enclose the target between the balls adjusting the pivots accordingly. Evidently the distance between these balls would indicate the angle at which the target is visible, i.e. the range (with a given size of a target).

The motion of the pivots can be transmitted immediately to the rheostat slide of the electromagnets of the sight-mechanism, so that the range would be fed in the sight-mechanism automatically. The gunner's task is limited to framing the target between the balls of the range finder. Since the target may assume different positions in relation to the gunner, several pivots with balls must be placed in the field of vision of the sight-mechanism, so that the target could be framed in any

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position. These mechanical devices restrict the gunner's field of vision. For that reason, optical instruments are used to scale the angular values of the target. The gunner sees only luminous pips which he can draw apart or pull together with the help of a special device enclosing the target so as to set the range. Let us see, how these luminous pips are produced in the field of vision and how they can be drawn together or removed from the sight axis.

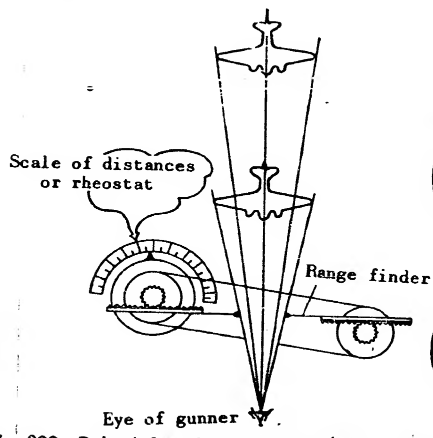

Fig.200 Principle of setting range in sighting.

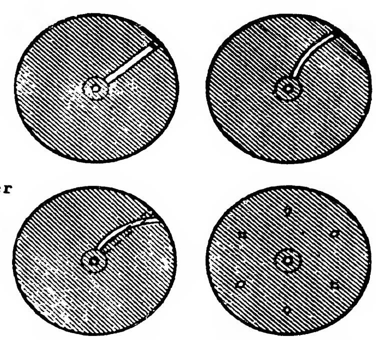

Fig.201 Design of luminous diamond-shaped pips of range finder.

Let us imagine two opaque disks. One of them had a radial slit and the other is provided with irregularly shaped slits. If each of these disks were illuminated individually, a luminous straight line would show on the first disk, and irregularly shaped slits on the second. If we placed one disk over the other and illuminated them, only a diamond-shaped rhombus would show where the straight cut intersects the irregularly shaped slits. If the disk with the straight slit remained stationary, the luminous rhombus would be shifted along the radial slit moving away from the center or approaching it in accordance with the direction in which the disk ~~turns. It is necessary to cut a corresponding number of slits on each of the disks, so that several luminous rhombuses would show along the circumference.~~

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If these disks were placed before the gunner, he would not see anything except the luminous pips. For that reason, the small rhombuses are built with the help of an optical device similar to that used for the construction of the grid of collimators.

After focusing the objective on the disks and letting the rays from the source of light pass through the openings in the disks, we could obtain an infinite image of the rhombuses on the reflector. The disk with the irregularly shaped figures could be attached with the help of a gear or rope drive equipped with a knob, so that the pilot could turn this disk at any angle to produce the luminous images of the diamond-shaped pips at the necessary distance from the grid center. The slides of the rheostats of the angle of lead and the angle of sight could also be connected with this know. The pilot would then feed in the range directly by turning the knob and frame the target by the diamond-shaped pips.

Inasmuch as the angular values of the target do not depend on its range but depend on its linear values, this operation can only serve to determine and set the range for one definite target size. However, without essential changes the above installation could be adjusted to register any range length. For that purpose, the disk with radial slits must also be mobile. Here are the results that we could obtain by proceeding in this manner:

Let us assume, that while the disk with straight slits is stationary, the disk with the irregularly shaped figures has to be shifted to a certain angle, so as to frame the target of a given size. This angle would correspond to the range of the target. If another larger target were placed at the same distance, the diamond-shaped pips would have to be moved apart more. To achieve this, the disk with the irregularly shaped figures has to be turned at a greater angle. Since the range is judged by the angle, at which the disk is turned, and since this turn is connected with the rheostat slides, the range fed in the sight-mechanism is greater than the actual range. Consequently, we must move apart the diamond-shaped luminous pips some more, while the angle at which the disk with the irregularly shaped figures

turns, would remain unchanged. This can be done by leaving the disk with the irregularly shaped figures in its original position while the second disk is turned in the opposite direction.

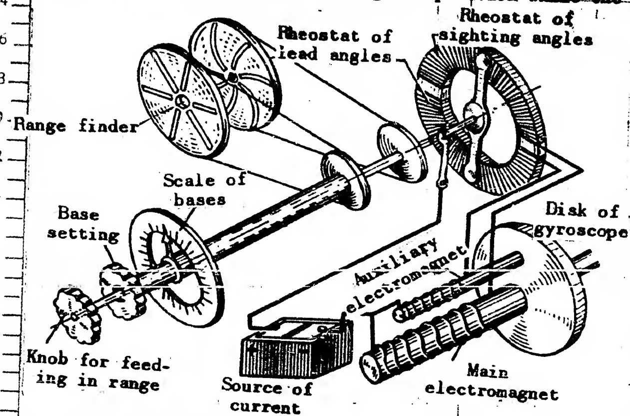

Fig.202 Range finder connected with slides of the rheostats of lead and sighting angles.

Thus, range corrections can be made by turning the disk. This disk may be connected to the scale so that the size of the target could be established in advance. Framing the target by the diamond-shaped pips would suffice to feed the actual range to the sight-mechanism as long as the disk with the radial slit is turned beforehand at an angle that corresponds to the size of the target.

This operation solves the task of setting the range.

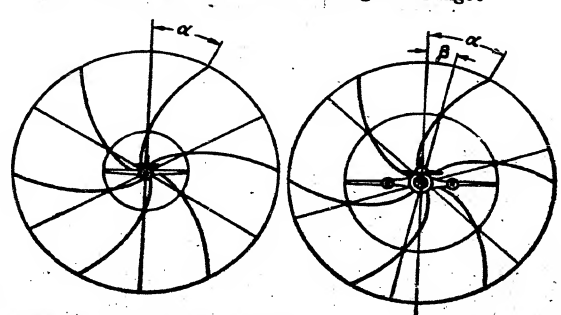

Fig.203 Setting base for range finder.

Let us study now the basic design and the simultaneous operation of the principal parts of an automatic sight-mechanism provided with the above

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characteristics.

104. Design of an Automatic Sight-Mechanism

The pilot must watch the diamond-shaped pips in the range finder and the clearly marked direction of the axis of the gyroscope in order to aline the axis of the gyroscope and to frame the target properly. At this point, it should be mentioned, that the diamond-shaped pips must be symmetrical in relation to the line of sight since in tracking the target the line of sight coincides with the target. The target, however, must be framed simultaneously by the diamond-shaped pips of the range finder. We know that the line of sight must always run parallel to the axis of the gyroscope and, therefore, the gunner's eyes must also be fixed on the diamond-shaped pips in a parallel direction relative to the axis of the gyroscope. A system of mirrors is used to form the axis of sight and to produce the diamond-shaped pips before the gunner's eyes. A round mirror is attached to the rear end of the axis of the gyroscope, opposite the metal disk, and another mirror is mounted on the sight-mechanism to direct the rays from the round mirror to the reflector. A third mirror serves as a reflector directing the rays into the gunner's eyes. The rays from the mirror that revolves with the gyroscope rotor are produced by a bulb. These rays pass first through the slits of the range finder disks, and through the openings in the centers of these disks. After passing through the central openings a ray strikes the round mirror and is reflected on the stationary mirror from where it is transmitted to the reflector. As it glances off the reflector, the ray hits the gunner's eye and the gunner sees the image of a luminous point along the entire length of this ray behind the reflector. If the axis of the gyroscope were parallel to the axis of the aircraft as the ray hits the gunner's eye, it will remain parallel to it at any turn. It is this sight ray that the gunner must bring in line with the target. Other rays from the bulb produce the images of the luminous diamond-shaped pips behind the reflect as they pass through the slits of the range finder disks. These diamond-shaped pips are symmetrical

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relative to the central luminous point. Thus, the whole grid composed of diamond-shaped pips and a central point shifts in the same direction and at the same angle as the axis of the gyroscope wherever it may turn.

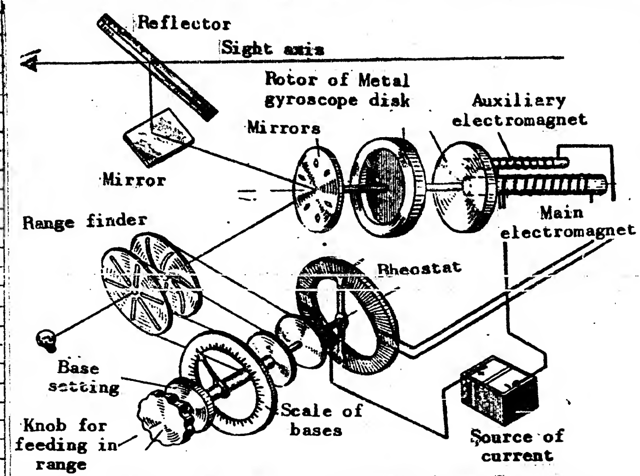

Fig.204 Design of automatic sight-mechanism in a fighter.

The range finder disk with radial slits turns with the help of a base setting handle. The disk with the irregularly shaped figures is connected with the knob of the range setting system and with the slide of the rheostat of the lead and sighting angles. At one end, this slide is shifted along the rheostat angle of lead, and at the other, along the rheostat angle of sight. The windings of the electromagnets are connected with the rheostat windings, so that any shift of the slide increases the resistance of the winding of one of the electromagnets, diminishing at the same time the resistance of the winding of another electromagnet. This happens because as the range increases, the angle of sight has also to be increased. Consequently, the strength of the current in the auxiliary electromagnet must also be increased, so that the axis of the gyroscope may deflect at a larger angle. The angle of lead formed by the gyroscope will be decreased as the range of firing increases, since the angular velocity of the target will diminish. It is, therefore, obvious that the angular velocity at which the aircraft turns will also decrease, and the axis of the gyroscope will lag behind the axis of the aircraft by a smaller

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angle while it should be lagging by a greater angle. To compensate for the decrease in angular target velocity with the increase of the range and to correct the increase in the time of flight of the projectile, the gyroscope must be allowed greater freedom. This is necessary to weaken the effect of the electromagnet of the angle of lead by weakening the current in the winding. As the range diminishes, the gunner has to move the diamond shaped pips pf the range finder apart so that the target is framed. He uses a handle for this operation. As the disk with irregularly shaped figures moves, the slide of the rheostats also moves. The strength of the current in the electromagnet of the angle of sight will be weakened while it will be intensified in the electromagnet of the angle of lead. Eventually, the angle of sight will become smaller since the eccentric force produced in the disk opposite the auxiliary electromagnet will be weakened. At the same time, the angle of lead will diminish as a result of boosting the magnetic field of the main electromagnet. Consequently, the braking effect upon the disk produced by the main electromagnet will increase provided that it is removed somewhat from the center of the disk causing it to precess at higher speed and follow the turn of the aircraft.

These are the principles used in the design of an automatic gun-sight mounted on stationary gun installations.

The principles upon which automatic sight-mechanisms on mobile installations are built do not differ greatly from the above design. We shall, therefore, refrain from discussing them here.

105. The Pilot's Task in Operating Automatic Sight-Mechanisms

Although automatic sight-mechanisms built to make allowance for relative target velocity relieve the pilot or gunner entirely from any calculations, the basic process of sighting is made somewhat more difficult. After the pilot identifies the point of lead with the help of a sight-mechanism that takes into account the absolute target velocity, he can maneuver the aircraft straight toward this point

and open barrage fire. With an automatic sight-mechanism he has to follow the target with the entire aircraft maintaining the line of sight on the target. The difficulty of the pilot's task consists in the fact that tracking is not done with the help of the axis of the aircraft but, to put it plainly, with the axis of the gyroscope which is not rigidly connected with the aircraft. A sharp turn of the contro wheels produces a "floating" in the field of vision of the point of aim according to which the axis of the sight-mechanism is adjusted and only a highly skilled pilot is able to maintain the mobile axis of the gyroscope steadily on the target while turning his aircraft. In all other respects, the pilot's operation is reduced to purely mechanical actions. Here is how he has to proceed:

1. After entering an area where an encounter with the enemy may be expected, the pilot turns on the electric system of the sight-mechanism about five to ten minutes before the anticipated combat so as to allow the gyroscope motor to run for five or ten minutes. This is necessary in order to establish the velocity at which the gyroscope rotates, and to bring about an adjustment of the axis of thegyroscope with that of the aircraft on the same vertical plane and under the angle of sight by the magnets of the angle of lead and the angle of sight respectively.

The diamond-shaped pips of the range finder must be moved apart as much as possible, i.e. their position must correspond to the maximum range. In this position of the range finder, the axis of the gyroscope is most "rigidly" connected with the axis of the aircraft and lags only by a minimum angle.

2. After identifying the target, the pilot establishes its size on the scale and without changing the position of the range finder, he maneuvers his aircraft so that the central point of aim coincides with the target.

3. Continuing to track the target with the entire aircraft and always maintaining the central point of aim on it, the pilot frames the target by the diamond-shaped pips of the range finder, bringing together the images and enclosing the target in a circle that the pilot imagines to run around the inner ends of the diamond

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shaped pips.

4. After the grid is steadily maintained on the target, the pilot opens fire and without letting the target out of the grid continues to fire until the target is destroyed. It goes without saying, that the number of rounds should not exceed the permissible one, so as not to disorient the guns.

There are the general principles of design and operation of automatic sight-mechanisms in aerial gun installations constructed to allow for relative target velocity.

Now, we shall report on the operation of gun-sights mounted on remote-control installations.

Chapter V

PRINCIPLES OF AUTOMATIC SIGHT-MECHANISMS IN REMOTE-CONTROL INSTALLATIONS

Mobile gun-installations in aircrafts serve primarily for defense and rarely for attacking purposes. For that reason, mobile gun installations are mounted so as to have maximum efficiency in case of attacks by pursuit planes.

There are several factors that decide the way in which mobile gun-installations are set up in an aircraft. Decisive, however, are the overall size and the purpose of a given aircraft.

There is no doubt, for instance, that a mobile machine-gun installation in a light bomber must be set up in the upper part of the aircraft to permit backward, sidewise and upward firing. It would be useless to set them up in the bottom part, since light bombers are low-flying planes and there is no possibility of attack from below by pursuit planes. Light bombers carry powerful defense weapons in front that are also used as defense weapons in case of attacks from below or in front from above by pursuit planes. In the first case, a light bomber may repel the attack and go into diving; in the latter, it may begin pitching. The flight features of a light bomber permit these maneuvers. Consequently, a light bomber is most exposed to attack from above in the rear. This fact should serve as the basis for the choice of the site and the angles for firing from mobile gun-installations.

Operating at higher altitudes than a light bomber a dive bomber is, therefore, exposed from below in the rear. Evidently, the defense system must be installed so as to permit rear and downward firing. The stationary machine-guns and cannons in this type of aircraft that fire forward, permit defense in the front and in the front from below, but do not permit repelling attacks in front from above, since the aircraft would have to nose up for this purpose while the properties and weight

of dive bombers make such operation impossible. Consequently, the gun-installation must be set up for forward and upward fire. For protection against attacks from above in the rear, a special installation is required. We see that to protect a dive bomber two mobile installations are necessary: a botton installation for downward and backward fire, and a ball turret installation for semi-spherical fire; three installations may also be set up: on the bottom to fire backward and downward, on top for upward and backward fire and in the nose for forward and upward fire.

Medium and heavy bombers are not equipped with stationary guns and carry mobile gun-installations for defense in every possible direction. The number and the set up of these installations also depend on various factors.

In attacks on ground troops and the nearest enemy rear bombers are usually accompanied by pursuit planes and carry only a limited number of guns.

Long-range bombers on missions must be equipped with powerful weapons regardless of whether accompanied by pursuit planes or not, so that they can repel attacks not only in one direction but in several directions simultaneously.

For efficient protection firing installations must sometimes be set up in places where a gunner cannot possibly be placed. It may, for instance, be necessary to set up gun-installations under the tail surface or under the wings of an aircraft. If the gunner were to service ball turrets placed on the botton part of the aircraft, he would have to be placed below the fuselage so as to have a roundabout view. This, however, would require an increase in the over-all size of the mobile installations which would, in turn, greatly affect the aerodynamic qualities and, primarily, the velocity of the aircraft.

Mobile installations are called "remote-control gun-installations." The gunner orients and controls the fire with the help of a system of mechanical drives as well as with electric and hydraulic gears set up at some distance from the installation.

Let us emphasize at this point that it is wrong to classify wing installations

in pursuit planes or light bombers as remote-control installations, since only the firing is regulated by remote control while sighting is done by maneuvering the entire aircraft.

Remote-control gun-installations require the use of regulating mechanisms in sighting by remote-control, of a series of electric devices as well as the application of a system of automatic blocking and signalling which complicates the operation greatly.

We have seen that the sighting operation and the directing of the guns is a rather simple task which the gunner is able to carry out independently when the sight is mounted directly on the gun and the gunner does not have to use any auxiliary devices to carry out this task. However, as soon as the gunner is removed from the installation, the task becomes much more complicated: the gunner can no longer orient the guns at his own discretion and is certainly unable to carry out the task.

We shall see now what makes it so complicated for the gunner to carry out the operations when he is removed from the gun-installations. We shall also discuss generally the tasks of sighting with the help of a remote-control gun-installation. We shall examine how the angles of sight are estimated and how sighting is done with these installations. In subsequent chapters we shall try to elucidate briefly these problems.

106. Peculiarities of Sighting and Adjusting in Remote-Control Gun-Installations

Automatic sight-mechanisms on remote-control gun installations are also based on the principle of accounting for relative target velocity.

We have already noted that the relative angle of lead ψ_r is measured by the product of the relative angular target velocity ω and time of flight of the projectile t, i.e.

$$\psi_r = \omega t.$$

Consequently, the automatic sight-mechanism that solves the above formula can

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only operate inasmuch as the relative angular target velocity is measured. If we pointed the axis of the sight at the target and would maintain the reticle of the gun-sight while it moves, the angular velocity at which the gun-sight turns relative the aircraft would, of course, precisely equal the relative target velocity. Therefore, all we have to do is to determine the angular velocity at which the gun-sight turns relative the aircraft while the target is tracked by the sight axis.

At this point, we cannot apply the reticle of the gun-sight following the apparent or actual movement of the target to establish the value of the relative or absolute lead as we have done in ring-type sight-mechanisms. The angular target velocity changes constantly; for that reason, corrections in the angle of lead formed by the sight-mechanism must be made constantly inasmuch as the angular target velocity changes. This is the first characteristic of sighting with the help of sight-mechanisms in remote-control and, generally, mobile gun-installations: throughout the sighting operation and control of the fire the sight axis must be continuously pointed at the target or, in other words, the reticle in the sight-mechanism must be continously maintained on the target.

Contrary to the automatic sights in pursuit planes and to the sight-mechanisms in ordinary mobile gun-installations, the angular target velocity is determined in the sight-mechanisms of remote-control installations in the form of its components in the horizontal and vertical planes, i.e. the angular velocity of the turn of the optical beam near the vertical axis and the angular velocity at which it turns near its horizontal axis are found separately. This second peculiarity of sighting with remote-control gun-installations results from the nature of combat activities of medium and heavy bombers. Contrary to fighters, light bombers and dive bombers they are in level flight in combat missions. That means that during a turn one of the sight axes is always in vertical position and it is, therefore, appropriate and practical the angular target velocity relative this axis and the one that is perpendicular. We refer to this characteristic as a "characteristic of

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sighting" instead of calling it a characteristic technique of measuring the angular target velocity, since the sight-mechanism actually not only accounts for the angle of lead in the direction of the visible target movement with this method of measuring the angular target velocity, but takes two angles into account: one in the vertical plane and the other in the horizontal plane.

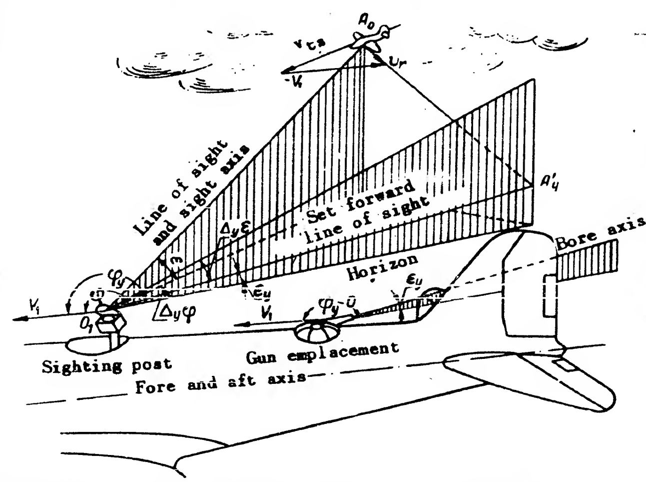

Fig.205 To allow for target velocity, it is necessary to make the bore of the machine-gun parallel to the set forward line of sight, i.e. to have it deviate from the fore and aft axes of the plane at an angle of ψ_y in the horizontal plane and of ξ_u in the vertical.

The third characteristic of sighting is a result of the so-called parallax position of the gun and the sight-mechanism, i.e. the displacement of the sight-mechanism relative the gun. This difference in position occurrs in the horizontal plane as well as in the vertical plane. The sight-mechanism may be shifted relative the gun along the longitudinal, normal and lateral axes. Since the lateral and normal axes of the aircraft fuselage are not very long, the lateral displacement of the sight-mechanism relative the gun would not be great; it is, therefore, disregarded and only the displacement along the longitudinal axis of the aircraft -which can be quite considerable- is taken into account. We shall, henceforth, refer to the distance between the sight-mechanism and the gun measured along the longitudinal axis of the aircraft as the parallax denoting it by letter p.

The parallax complicates the general firing operations to a great extent. We shall see below what the nature of these complications is.

Contrary to firing operations in a fighter, the lag of the projectile has to be taken into account in firing from mobile installations. This is the fourth characteristic of sighting with sight-mechanisms in remote-control installations or in mobile gun-installations.

Let us study now the general plan of sighting with sight-mechanisms in a remote-control gun installation (Fig. 205).

Let us assume that at a given moment the target is in point A_o travelling with velocity v_u on a parallel approaching course with the gunner's aircraft that flies at speed V_1. The gunner and the sight-mechanism are in point O_1 while the gun is in point O. The position of the target relative the gunner at every given moment is determined by the following angles: hull angle of the target φ, i.e. the horizontal angle between the axis of the aircraft and the vertical drawn through the target and the axis of the sight-mechanism; angle of site ε, i.e. the vertical angle between the horizontal and a line joining the target and by range D, i.e. distance O_1A_o from the sight to the target.

To form the relative angle of lead we must find out relative target velocity v_r. This can be done by adding the velocity vector of the aircraft directed in the opposite direction to the vector of absolute target velocity v_u. Relative set forward point A_y' will be located along the vector of relative target velocity v_r and at a distance from point A_o equal to the product of relative target velocity multiplied by the time of flight of the projectile, i.e.

$$L_r = A_oA_y = v_rt.$$

If the gun were also located in point O_1 and the trajectory of the projectile would be rectiangular without descending or lagging the axis of the gun barrel must also be aimed at point A_y' along line O_1A_y' in order to hit the target. In

other words, in order to hit the target, the gun barrel must be deflected from line O_1A_0 that joins the target by angle $\Delta_y\varphi$ in the horizontal and by angle $\Delta_y\varepsilon$ in the vertical. The gun barrel would then assume a position relative the axis of the airplane and the horizontal plane denoted by angles

$$\varphi_y = \varphi + \Delta_y\varphi$$
$$\varepsilon_y = \varepsilon + \Delta_y\varepsilon.$$

To orient the gun barrel properly under the above circumstances corrections $\Delta_y\varphi$ and $\Delta_y\varepsilon$ must be made in the angles that determine the site of the target.

Correction $\Delta_y\varphi$ is called angular correction in the lead to the bull angle, and correction $\Delta_y\varepsilon$ is known as the angular correction in the lead to the angle of site. Essentially, these corrections are the components of the relative vertical angle of lead in the vertical and horizontal planes. They may be either positive or negative depending on whether they increase or decrease the angles that determine the site of the target. In our case the correction in the angle of site $\Delta_y\varepsilon$ is negative and when added to the angle of site it must denoted with a minus.

The gun is not in point O_1, but has moved relative this point to point O by the vallue of parallax p. For that reason, the axis of the gun will be parallel to the set forward line of site O_1A_0 if the gun formed angles φ_y and ε_y. The projectile would not pass through point A_y', but would pass it at a distance equal to the value of parallax p. Consequently, the existence of the parallax requires that the gun be turned some more horizontally and vertically so as to orient its axis toward relative set forward point A_y'.

Without changing anything in the position of the sight and of the gun, let us consider some other factors that affect firing operations with mobile installations.

In firing from mobile installations the projectile lags under the angle formed by the axis of the airplane, i.e. there is an apparent deflection of the trajectory toward the tail of the aircraft. We have already mentioned that the gun-barrel

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must be deflected from the set forward line of site in direction of the flight of the aircraft so as to allow for the projectile lag, i.e. the adjusting point of the gun-barrel must be shifted from the relative set forward point by the distance that equals the lag value (Fig.206). If the gun were at point O_1 the axis of the gun-barrel would have to be oriented along line O_1A to allow for target movement and projectile lag and the piece be turned furthermore relative line $O_1A'_y$ in the horizontal plane by angle $\Delta_z\psi$, without deflecting it in the vertical plane. Thus, the gun-barrel will be in a position defined by angles ψ_z and ξ_z relative the aircraft.

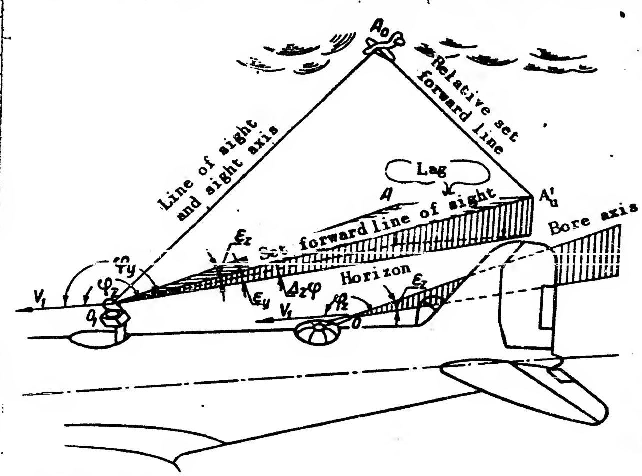

Fig.206 To allow for projectile lag z, it is necessary to have the bore of the machine-gun parallel to line O_1A, turning it furthermore at an angle of $\Delta_z\psi$ in the horizontal plane. The position of the piece with account of target velocity and lag will be defined by angles ψ_z and ξ_z.

Angle ψ_z in the horizontal plane will be formed if angular correction is made in the lag to the hull angle of the target $\Delta_z\psi$, and this correction added to angle ψ_y. With a minor error, angle ξ_z can be considered equal to angle ξ_y.

Since the piece is in point O instead of being in point O_1, we would make the bore axis parallel to line O_1A by forming the angles of sight ψ_z and ξ_z.

The angles that definite the position of the gun-barrel relative the gunner's aircraft and with allowance for target velocity and projectile lag would now be

$$\psi_z = \psi_y + \Delta_z \psi$$

and

$$\varepsilon_z = \varepsilon_y .$$

But since $\psi_y = \psi + \Delta_y \psi$ and $\varepsilon_y = \varepsilon + \Delta_y \varepsilon$, we shall obtain

$$\psi_z = \psi + \Delta_y \psi + \Delta_z \psi$$

and

$$\varepsilon_z = \varepsilon + \Delta_y \varepsilon .$$

We see that corrections $\Delta_y \psi$; $\Delta_z \psi$ and $\Delta_y \varepsilon$ must be made to allow for target velocity and projectile lag in the angles of sight ψ and ε and form the angles obtained by these corrections with the gun-barrel.

The bore axis would have a position parallel to the line O_1A. After its release the projectile will pass through point A_y' at a distance equal to the linear value of parallax p.

Under the effect of gravity the projectile falls below the line of departure (Fig. 207). For that reason, it will pass below point A at a distance equal to projectile fall s if it departed along line O_1A. To allow for the projectile fall the bore of the gun must be directed (provided that it is in point O_1) along line O_1B while the adjusting point is displaced above point A by the value of projectile fall s or, in other words, the bore of the gun is turned relative to line O_1A upward by angle $\Delta_s \varepsilon$, without changing hull angle ψ_z.

Now, the position of the piece relative the aircraft is defined by angles ψ_s and ε_s and angle ψ_s will equal angle ψ_z.

Since the piece is in point O its axis will be prallel to line O_1B after angles ψ_s and ε_s are formed.

We shall find angles ψ_s and ε_s after making correction to allow for the fall in the earlier obtained angles ψ_z and ε_z.

We shall obtain

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$$\psi_s = \varphi_z$$

and
$$\xi_s = \xi_z + \Delta_s \xi ,$$

but $\psi_z = \psi + \Delta_y\psi + \Delta_z\psi$ and $\xi_z = \xi + \Delta_y \xi$, therefore

$$\psi_s = \psi + \Delta_y\psi + \Delta_z\psi$$
$$\xi_s = \xi + \Delta_y\xi + \Delta_s\xi ,$$

We see that finally, after allowing for target velocity, and the lag and fall of the projectile, the bore of the gun is parallel to the line O_1B. For that reason, the projectile falling under the effect of gravity at a distance BA=s and lagging under the action of the actual velocity of the aircraft at a distance AA_y=Z will not hit relative point of impact A_y', but will pass it at a distance equal the value of parallax p. To have the projectile hit relative point of impact A_y' the bore of the gun must be pointed to point B by turning the axis of the bore further from position OC by angles $\Delta\rho\psi$ and $\Delta\rho\xi$ (Fig.208) instead of adjusting it to the parallel line O_1B.

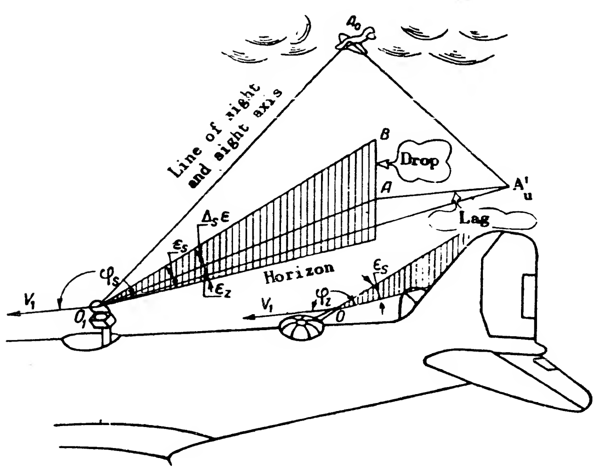

Fig.207 To allow for gravity drop, it is necessary to have the bore of the machine gun parallel to line O_1B, turning it furthermore upward at an angle of $\Delta_s \xi$. The position of the piece with account of target velocity, lag and gravity drop is defined by angles ψ_z and ξ_s.

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After this additional turn, the bore of the gun would be in position OB, defined by the final angles of **elevation** -- the relative hull angle of the piece v_o and the relative angle of elevation θ_o.

To form angles v_o and θ_o corrections $\Delta_p\psi$ and $\Delta_p\varepsilon$, known as angular parallax corrections, must be added to the earlier formed angles ψ_s and ε_s, in conformity with the hull angle of the target ψ and the angle of site of target ε.

Now, the projectile departing in direction OB will fall by distance BA = s under the effect of gravity; furthermore, it will lag by distance $AA_y' = z$ and pass through relative point of impact A_y'; while the projectile is in flight, the target will also reach this point.

The angles of elevation v_o and θ_o could be established according to

$$v_o = \psi_s + \Delta_p\psi$$

and

$$\theta_o = \varepsilon_s + \Delta_p\varepsilon ,$$

but we have established that $\psi_s = \psi + \Delta_y\psi + \Delta_z\psi$, and $\varepsilon_s = \varepsilon + \Delta_y\varepsilon + \Delta_s\psi$, therefore, we shall finally obtain

$$\boxed{\begin{aligned} v_o &= \psi + \Delta_y\psi + \Delta_z\psi + \Delta_p\psi \\ \theta_o &= \varepsilon + \Delta_y\varepsilon + \Delta_s\varepsilon + \Delta_p\varepsilon \end{aligned}} .$$

We see, that in order to find the relative hull angle of elevation ψ_o, the corresponding corrections in lead $\Delta_y\psi$, in lag $\Delta_z\psi$, and in parallax $\Delta_p\psi$ must be added to the hull angle of the target. To find the relative elevation θ_o the correction in lead $\Delta_y\varepsilon$, in the projectile fall $\Delta_s\varepsilon$ and in parallax $\Delta_p\varepsilon$ has to be added to the angle of site of the target.

Thus, when the sight axis is in position O_1A_o, the bore axis must be in position OB. The piece must occupy this position as a result of tracking the target with the axis of the sight before it approaches point A_o. This happens because the angular target velocity has to be established to make the correction. However, the angular target velocity can, in turn, be defined as the angular velocity of the turn of the sight. That means, that the target has to be tracked for a certain

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time by the sight axis so as to establish this angular velocity and to measure it.

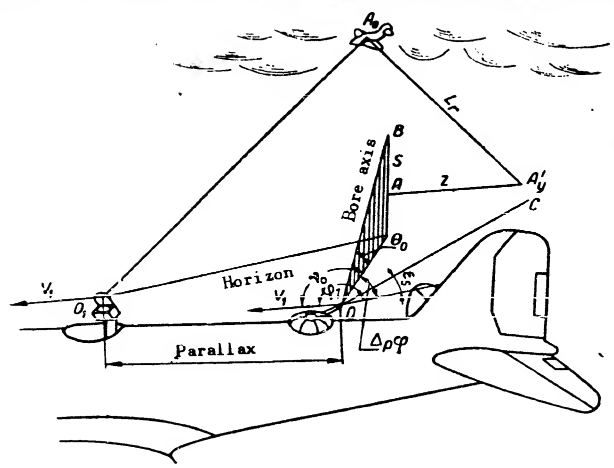

Fig.208 To allow for parallax, it is necessary in addition to turn the bore of the machine gun at an angle of $\Delta_p\psi$ in the horizontal plane and $\Delta_p\xi$ in the vertical, and direct it at boint B. The position of the piece with account of all factors is defined by angles γ_o and θ_o.

Position OB of the bore of the gun corresponds only to the moment at which the sight axis is in position A_1O_o. As soon as tracking the target with the sight axis is done along A_oA_y', the bore of the gun must assume other positions according to the new firing conditions which change as the relative target movement changes.

In the process of tracking the target with the sight axis, special mechanisms must allow for corrections $\Delta_y\psi$, $\Delta_z\psi$, and $\Delta_p\varphi$ to the hull angle of the target in accordance with firing conditions and with the nature of the target movement. Corrections $\Delta_y\xi$, $\Delta_z\xi$ and $\Delta_p\xi$ to the angle of site of the target must also be made. Unless these corrections are signalled to the firing installation, the piece is connected with the sight-mechanism so that its axis always remains parallel to the axis of sight regardless of how the sight may turn; the angles of aim of the guns precisely equal those of the sight-mechanism, i.e. correspond to

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the hull angle of the target ψ and the site angle of the target ε. This applies to what we may call a rough aiming of the guns. Signalling the angular corrections to allow for lead, lag, fall and the parallax, of the piece must turn additionally at angles $\Delta_y\psi$, $\Delta_z\psi$, and $\Delta_p\psi$ in the horizontal plane and by angles $\Delta_y\varepsilon$, $\Delta_z\varepsilon$, and $\Delta_p\varepsilon$ in the vertical plane occupying the position necessary to hit the target. Since firing conditions change continuously, these corrections must also be made continously and signalled to the installation.

Thus, in tracking the target continuously, the gun bore must be always in a position to make the released projectile pass through the relative point of impact.

The difficulty of the task of sighting is, essentially, the need to compute all necessary corrections. A special mechanism is available to compute each of these corrections. It determines the correction either independently or in interaction with other mechanisms in accordance with the firing conditions transmitted to the mechanism signalling it to the firing installation.

It is impossible at this point to study each of these mechanisms since the working principles of the decisive mechanisms exceed the scope of this book.

We shall confine ourselves to reporting on the general operation of aiming the guns briefly referring to the principles of computing the corrections and signalling them to the firing installation.

Thus, the main task of an automatic sight-mechanism in remote-control gun installations consists in computing corrections in sighting angles.

Let us see how this is being done.

107. How to Compute Corrections for Pointing Angles of Guns

To begin with, we shall compute the basic corrections for pointing angles to report on the principles of computing corrections, i.e. we shall start with corrections for the lead $\Delta_y\psi$ and $\Delta_y\varepsilon$.

Corrections for the lead $\Delta_y\psi$ and $\Delta_y\varepsilon$ are angles at which the axis of the viewer turns in horizontal or vertical direction in tracking the target while the projectile

is in flight. In fact, if a projectile were released while the target is at point A_o and it hits the target in point A_y, it follows that during the time of flight of the projectile, the optical beam that is directed at the target, has turned by angle $O_oO_1A'_y$ and would also be directed at point A'_y at the moment of impact. Angle $A_oO_1A'_y$ at which the optical beam of the viewer is turned in the plane of the visible target movement, is formed by turning it at horizontal angle $\Delta_y\psi$ and vertical angle $\Delta_y\varepsilon$. In both planes, the viewer beam turns with a certain angular velocity. We shall denote the angular velocity of the turn of the viewer beam by ω_ψ in the horizontal plane and ω_ε in the vertical. Then, the horizontal angle at which the viewer beam is turned during the flight of the projectile is $\Delta_y\psi = \omega_\psi t$, and the vertical angle would be expressed by $\Delta_y\varepsilon = \omega_\varepsilon t$.

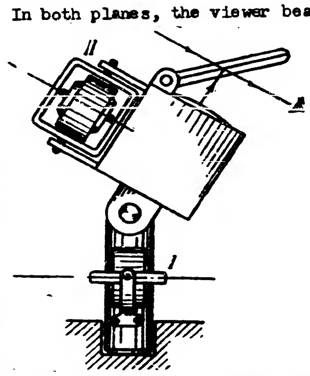

Fig. 209. The angular velocities of the vertical and horizontal rotation of the viewer are determined by means of two gyroscopes.

Consequently, to compute the angular correction for target velocity, we must know the angular velocity at which the viewer beam turns in the vertical and horizontal planes during the time of flight of the projectile.

How can these values be determined?

To determine the angular velocities of the turn of the viewer beam, we use two gyroscopes connected with the viewer in the sight-mechanism. One of the gyroscopes I (Fig. 209) is connected with the vertical rod of the viewer and serves to establis[h] the angular velocity at which the viewer beam is turned in the horizontal plane. Gyroscope II is connected with the the upper part of the viewer and serves to determine the angular velocity of the viewer beam in the vertical plane.

Both gyroscopes have two degrees of freedom, i.e. their frames may turn only i[n]

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plane -- either the vertical or the horizontal. The axis of the frame of the lower gyroscope is perpendicular to the vertical axis at which the viewer turns; that of the upper gyroscope -- to the horizontal axis.

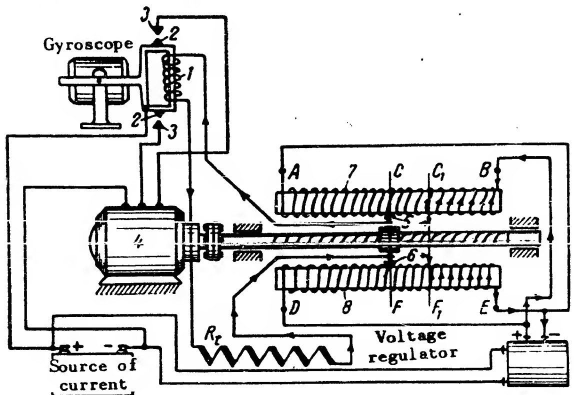

Fig.210 Diagram of device allowing the determination of angular correction on target velocity.

In stationary viewers the axis of the upper gyroscope is parallel to that of the viewer while the axis of the lower gyroscope is on the same vertical plane with the axis of the viewer and perpendicular to its vertical axis of rotation. Pivots that are passed through solenoids I -- the latter are connected with the viewer -- are attached to the frames of the gyroscopes along the rotor axes. (Fig.210). Each pivot carries movable contact 2 at its end. This movable contact is enclosed by two stationary contacts 3 which are also connected to the viewer.

For a better understanding of the principle of determining angular velocities at which the viewer turns, let us examine the action of the lower gyroscope that is connected with the vertical rod of the sight-mechanism and scales the angular velocity of the turn of the viewer beam in the horizontal plane.

As the viewer turns about the vertical axis, a sight holder on which the frame of the gyroscope is attached turns along with the viewer about the same axis.

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We know that under the effect of any force upon the frame or the axis of the gyroscope, the axis of the gyroscope will rotate in a direction perpendicular to the direction in which these force acts. We also know that the greater the velocity, the greater the acting force. Consequently, in our case here the axis of the gyroscope will deflect either upward or downward depending on the direction in which the rotor of the gyroscope revolves.

As soon as the frame of the gyroscope deflects from its neutral position, one of the stationary contacts 3 will close and motor 4 will be set into motion. If the [illegible] contact closes, the motor revolves in one direction and if it is the lower contact, the motor revolves in another direction.

With the help of a screw contact brushes 5 and 6 of potentiometers 7 and 8 are set into motion from the motor shaft; the potentiometers are switched into the direct current mains through a voltage regulator. The contact brushes are connected by solenoid I and the so-called projectile flight time circuit R_t; the resistance of the latter in a certain scale represents the time of flight of the projectile under given firing conditions.

When contact brushes 5 and 6 are in neutral position CF, the winding of the solenoid is deenergized since the voltage in points C and F is identical. A brush lead in position C_1F_1 will increase voltage in point C_1 more than in F_1 since the since the resistance to the current from the positive pole of the source of the current has increased by an increase in sector DF by value FF_1 in potentiometer 8 and decreased in potentiometer 7 by a decrease in sector CB by value CC_1. For that reason, the brush lead in position C_1F_1 will produce a current flowing along the circuit of the solenoid in the direction indicated by arrows on the diagram. If another contact 3 closes, the motor will revolve in the opposite direction, the brush lead will take place to the left and the current in the solenoid circuit will begin to flow in the reversed direction. The motor continues to revolve as long as one of contacts 3 is closed. That means that with a closed contact 3 the contact brushes will be [illegible] shifted, the potential difference between points C_1 and F_1 will in-

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crease and an increasingly intense current will flow along the solenoid winding. The current intensity will increase until the magnetic field of the solenoid will open the contacts returning the frame of the gyroscope to neutral position between the contacts.

After the contacts are opened the motor will stop, but since the contact brushes will remain displaced, a current will continue to flow along the solenoid winding and if the strength with which the frame of the gyroscope strives to turn will not change, the frame will be maintained in neutral position between the contacts. This position will be achieved if the angular velocity at which the viewer turns and, consequently, the angular target velocity remain constant. An increase in the angular target velocity would bring about a greater angular velocity at which the viewer turns, the gyroscopic moment would increase and the frame would close at the same contact. The motor will start working again, the contact brushes will be shifted even farther, and the intensity of the current in the solenoid circuit will be increased until the contacts reopen, i.e. until the position of the potentiometer slide will not be adjusted to the angular target velocity. Should the angular target velocity decrease, the gyroscopic moment of the gyroscope would also decrease, the magnetic field would be excessive and close the frame of the gyroscope to the opposite contact. The motor will be imparted a reversed revolution shifting the contact brushes back, weakening the current intensity in the solenoid winding until the contacts reopen. When the rotation of the viewer stops the brushes are shifted into neutral position and the current in the solenoid circuit will stop flowing, the frame will be placed into central position. This happens after the contacts are closed under the effect of the excessive magnetic field.

In the system discussed here, the magnetic field of the solenoid always balances the gyroscopic moment of the gyroscope; consequently, the position of the slides 5 and 6 of the pontentiometers indicates the value of the angular target velocity.

Thus, the distance of the slides from neutral line CF is, at a certain scale, the angular target velocity in the horizontal plane.

The upper gyroscope functions in the same manner. There, too, the angular target velocity in the vertical plane is obtained in the form of the shifts of the slides of the potentiometers from the central line.

We have now found the angular target velocities in the vertical and in the horizontal planes. What we need, however, are not the angular target velocities but the angular corrections for its movement.

To obtain corrections $\Delta_y \psi$ and $\Delta_y \varepsilon$ we must know how to determine the time of flight of the projectile and then, multiplying it by the found angular velocities we shall determine the corrections.

Let us assume that we know how to estimate the time of flight of the projectile. We shall denote it in the form of a variable resistance R_1, a sector in the solenoid circuit. This resistance will be changed proportional to the computed time of flight of the projectile. Since resistance R_1 is switched in the solenoid circuit in series it is obvious that the greater its value, the weaker the current intensity that flows in the solenoid winding and the weaker the magnetic field; the slides of the potentiometers would have to be moved farther away to turn the deflected frame of the gyroscope to its central position.

At decreased time of flight of the projectile resistance R_1 will also diminish, and the slides of the potentiometers will be displaced less. Thus, the distance at which the slides of the potentionmeters are moved from their neutral position, will indicate the angular correction for the target velocity in a certain scale instead of showing the angular target velocity. In fact, the correction for the movement of the target depends from the time of flight of the projectile and increases along with it. In our device the shift of the brushes of the potentionmeters increases with increased resistance R_1. That means, that considering resistance R_1 in a certain scale as the time of flight of the projectile we can, resorting again to the

an appropriate scale, consider the change in the position of the brushes as the angular correction for the velocity of the target movement.

Thus, our device automatically determines the angular target velocity computi directly the angular correction for the lead after the time of flight of the proje tile is fed to this de vice.

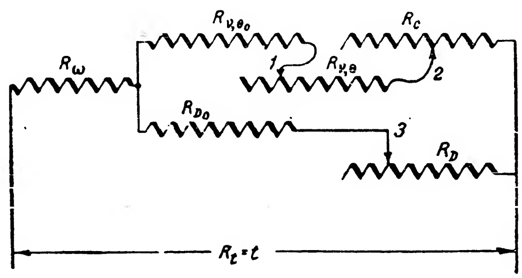

Fig.211 Projectile flight time circuit. This system of rheostats allows the expression of projectile flight time in amperage.

Let us examine no one of the methods tha serve to establish the time of flight of the projectile.

From the above de sign we have seen tha it is most efficient visualize the time of flight of the project as a certain resistan circuit. Let us try to imagine it precisely in this manner.

The time of flight of the projectile depends primarily on the range of firin It increases as the range increases. Let us assume that slide 3 of rheostat R_v i connected with the range finder of the sight-mechanism similar to the range finde used in fighters. As the disk with the irregularly shaped slits turns the rheosta slides moves at a distance that is not proportional to the angular move of the di but by a few irregular gears the distance is proportional to the change of the ti of flight of the projectile that occurs as the range changes. For that purpose, t profiles of the pattern gears must be chosen correctly.

By framing the target while tracking it with the diamond-shaped pips, we cr rheostat resistance R_v that will be proportional to the time of flight of the pr

jectile at a given range.

This rheostat would suffice to feed the time in the sight-mechanism in the form of resistance if the time of flight of the projectile did not depend on anything else. But the time of flight depends on a whole series of factors. The quoted ballistic coefficient $c_h = c. \Delta$, is one of these factors; it depends on the relation between the density of the air at the altitude of firing and at sea level since

$$\Delta = \frac{\Pi h}{\Pi o} \quad .$$

The density of the air depends on atmospheric pressure p and temperature T. That means, that in the final analysis the above ballistic coefficient for a given projectile depends on the atmospheric pressure and the temperature of the air. Consequently, the sight must include a special device to compute the ballistic coefficient in accordance with the temperature and pressure signalled to it, showing the coefficient in the form of a mechanical move. In the projectile flight time circuit this mechanical move is transmitted to slide 2 and is transformed into rheostat resistance R_c. As the above ballistic coefficient decreases, the time of flight of the projectile also decreases. This takes place according to a complicated law.

At the same time, the time of flight of the projectile depends on the initial velocity of the projectile, the velocity of the aircraft and the sighting angles v and θ. That means, that a special device must be built into the sighting-mechanism to account for the dependence on the time of flight of the projectile on all these factors in the form of some mechanical shift. In the projectile flight time circuit this mechanical shift is transmitted to the slide of rheostat $R_v\theta$, and the time factor, or rather its dependence upon the above factors, is indicated by the rheostat resistance $R_v\theta$.

The time of flight also depends on the range and height of firing, the velocity of the aircraft and a complex of other factors, but not on individual factors. We find that this dependence is most efficiently expressed by the formula

$$R_1 = \frac{R_1 R_2}{R_1 + R_2}.$$

As readers will remember from their course in physics, this formula represents general resistance R_1 of the electric circuit that is composed of two resistances R_1 and R_2 switched in prallelly.

If we consider R_1' equal $R_c + R_{v\theta}$, and R_2' equal RD, the resistance of this circuit will, with a certain scale, determine the time of flight of the projectile. We have mentioned earlier, that the adduced formula is most suited to express the dependence of the time of flight of the projectile on the factors that influence it, but that does not imply that this dependence is expressed precisely. To compensate for errors, constant resistances R_{D_0} and $R_{v\theta}$ are switched in the parallel shunts. In addition -- since the projectile flight time circuit is switched in the solenoid circuit -- resistance R_ω of the regenerated solenoid that is automatically switched in the time circuit and must, therefore, be taken into account when data are computed to determine the timeof flight of the projectile.

Thus, the time of flight of the projectile is obtained as a sum of recistance R and two resistances R_1 and R_2 switched in parallelly. Resistance R_1 equals $R_1 + R_{v\theta} = R_{v\theta} + R_c + R_{v\theta}$ and is known as the ballistic shunt of the circuit. $R_2 = R_2 + R_D = R_D + R_{D_0}$ is referred to as the range shunt.

Corrections in the lead and the elevation are computed by this complicated method.

Let us examine now one of the methods to compute corrections in the projectile fall and lag. These corrections are known as ballistic corrections. They are computed by a ballistic director also known as the ballistic center of the sight-mechanism.

We can find formulas of correction in the scheme of sighting to allow for lag $\Delta_2\varphi$ and for descent of the projectile $\Delta_3\varepsilon$; these formulas are:

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$$\Delta_z\varphi = -\frac{z \sin\varphi}{D \cos\theta}$$

$$\Delta_s\varepsilon = \frac{s \cos\theta}{D}.$$

In addition to ranging angles φ and θ of range D that are known these formulas include lag z and fall s. These two values can also be expressed by formulas that reflect their dependence on range D, the above ballistic coefficient c_H, the aircraft velocity V_1 and the relative velocity of the projectile v_0.

In addition to corrections for the fall and lag of the projectile the ballistic mechanism transmits to the projectile flight time circuit the correction for deflections through a special rheostat, i.e. allows for the actual velocity of the aircraft inasmuch as it affects the time of flight of the projectile.

To solve the above formulas, the ballistic device may be constructed in the form pf a joint installation, that has rod 1 at its lower extremity. It swings in ball joint 2 (Fig. 212). The upper extremety of the rod is connected with crank 4 with the help of connecting rod 3. The axis of rotation of the crank (1-1) can turn near the perpendicular axis II-II. Joint 2 can be moved along rod 1 by screw 5.

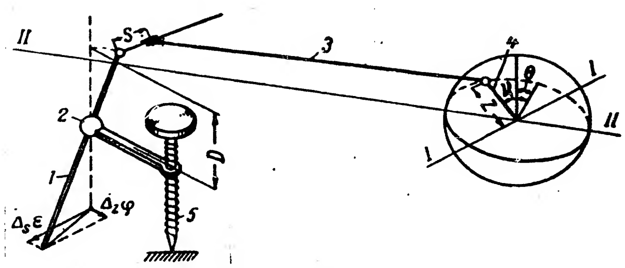

Fig. 212. Ballistic device. This device allows to obtain corrections for projectile lag and drop in the form of displacements of the lower extremity of rod 1.

If the length of crank 4 were variable and equal to projectile fall s, while the lateral displacement of rod 1 relative axis II-II would also be made variable and equal to the fall of projectile s, and the distance from the upper point of

strengthening of rod 1 to the ball joint 2, would also be equal at each given moment of the range of firing; the lower extremity of the rod will move to a certain point A at distance Δ_ω provided that crank 4 is turned at an angle equal to the hull angle of the piece ψ, and its axes II near axis II-II by an angle equal to angle of elevation θ. If we decomposed this vector $\Delta\omega$ along axis II-II and perpendicular to it, we shall obtain corrections $\Delta_z\psi$ and $\Delta_o\varepsilon$. Thus, signalling the lag in the form of the length of crank 1, the projectile fall in the form of distance s, and the range in the form of the angular turn of screw 5, to the device, we shall obtain the angular corrections for lag and fall by turning crank 4 near axes I-I and II-II at rough angles of pointing ψ and θ, which correspond to ψ and ε.

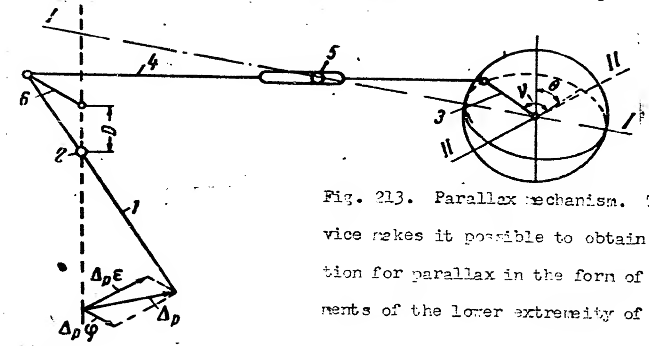

Fig. 213. Parallax mechanism. This device makes it possible to obtain correction for parallax in the form of displacements of the lower extremity of rod 1.

Parallax corrections can be computed in the same manner as above. In the scheme of sighting, parallax corrections are expressed by formulas:

$$\Delta_p\psi = \frac{p \sin v}{D \cos \theta},$$

$$\Delta_p\varepsilon = \frac{p \cos v \sin \theta}{D}.$$

The parallax mechanism (Fig. 213) can be constructed as a joint installation, that also has rod 1 at its extremity which can turn in joint 2. The upper part of the rod is connected with crank 3 through crank 6 and connecting rod 4. Crank 4 can turn about axis II-II and together with connecting rod 4 and crank 6 about

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axis I-I.

The length of crank 3 is constant and in a certain scale equals the parallax while the distance from the axis of rotation of crank 6 to the ball joint 2 equals the range of firing.

If crank 3 were turned now about axis II-II by an angle that equals the hull angle Ψ, and the entire system about axis II-II by an angle that equals elevation θ, the lower extremity of rod 1 will be displaced by a distance proportional to the parallax angular corrections $\Delta_p\varphi$ and $\Delta_p\varepsilon$.

This will close our very rough report on the principles of automatic computation of angular corrections in ranging the guns. We shall study now the necessary adjustments of the guns so that the ranging angles could be formed and the target hit.

108. Outline of Remote-Control Systems of Transmission

A number of values must be transmitted to the decisive mechanisms in the sight to compute the corrections allowing for the angles of ranging the guns. These values are either calculated by other devices or transmitted from the mobile units of the sight-mechanism.

These data sometimes have to be obtained in the form of mechanical linear displacements, sometimes as angles of turn and occasionally as electrical values.

When the mechanism that receives one value or another is not far from the one that transmits these values, the process does not involve any difficulties and can be carried out by any of the mentioned methods.

This task is much more complicated when it comes to transmitting a value in the form of a mechanical displacement at considerable distance such as, for instance, signalling the angles of range of the pieces computed by the computer to the firing installation. It is just as complicated to transmit the angles at which the viewer of the sight-mechanism turns to the computer that is usually located at some distance from the viewer. The same applies to the transmission of the range to the

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target. A transmission system composed of shafts and gears would be impractical, as it is too heavy and permits considerable errors to occur in the data that have to be transmitted. For that reason, a so-called remote control system of transmission is used. In this system, mechanical displacements for the transmission of data are converted into electrical values. Eventually, they are reconverted into mechanical values in the receiver.

The potenticmeter and selsyn remote control system are the most popular system.

The potentiometric remote control system consists of two parallelly switched in potentiometers with slides that are connected by an amplifier (Fig.214).

If an electric current were passed through this system, it would derive at point A, flowing in circuit $0-1-2-3-0_1$, and circuit $0-1'-2'-3'-0_1$. If the angles of deflection a and d_1 of the potentiometer slides were equal, there would be no current in conductor AB, since in points 2 and 2' the potentials will be equal.

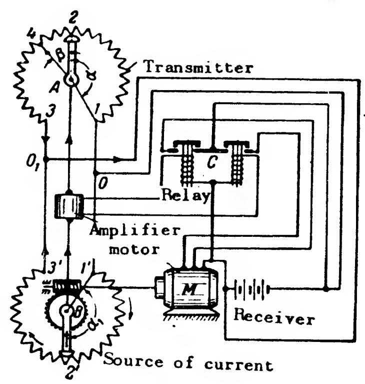

Fig.214 Diagram of potentiometric remote control system.

Let us assume, that the slides of the potentiometer transmitter is deviated further by angle β. Then, resistance in sector 0-1-2-4 will already exceed the resistance in sector 0-1'-2' and heavier current will flow in the receiver circuit than in the transmitter circuit. But only part of the current will pass point 2' reaching point 3' and 0_1. Most of it will flow in circuit 2'-B-A-4-3-, since the resistance in sector 4-3 has become weaker than the resistance in sector 2'-3'.

The current produced in conductor AB is known as the signla. It is intensified with the help of an amplifier and is transmitted to one of the electromagnetic type

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relays C that starts motor M. The motor is [illegible] moving the slide of the potentiometric receiver, until it is deflected by the same angle as the slide of the potentiometric transmitter. The current in conductor AB will be cut off as soon as the angles at which the slides turn become equal, the relay will open shutting off the motor. As the slide of the potentiometric transmitter is shifted in the opposite direction setting off another relay the motor will move the slide of the receiver also in the reversed direction. Thus, the angle at which the slide of the receiver turns, will always correspond to the angle at which the slide of the transmitter turns.

With the help of potentiometric remote-control systems, the range from the viewer to the target, the above ballistic coefficient of the projectile and the actual speed of the own aircraft, can be transmitted to the computer in the sight-mechanism.

The basic components of the selsyn remote-control system are the selsyn transmitter and the selsyn receiver. Both are specially constructed motors.

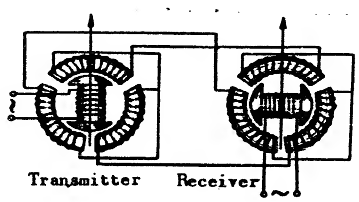

Fig. 215. Diagram of wiring of rotor and stator windings in selsyn remote-control system.

The principles of the selsyn remote-control system are as follows: Alternating current enters the rotor winding of the selsyn transmitter. Under the effect of the alternating current an alternating magnetic field is produced, its direction depending on the position of the rotor. At every phase of the stator winding of the transmitter the alternating magnetic field directs the electromagnetic force. The stator winding of the selsyn transmitter is connected with the stator winding of the selsyn receiver. Consequently, a magnetic field is also produced in the selsyn receiver, its directions strictly complying with that of the selsyn transmitter. If the position of the rotor of the

receiver does not correspond to that of the rotor of the transmitter, signal voltages would be produced in its winding, their intensity and direction depending on the intensity and direction of the displacement of the rotor of the transmitter relative the rotor of the receiver. These signal voltages are transmitted to the amplifier, and after amplification control the motor that places the rotor of the receiver in a position that corresponds to the position of the rotor of the transmitter. The signal voltages disappear as soon as the rotor of the selsyn ~~transmitter~~ receiver is perpendicular in relation to the rotor of the selsyn transmitter while stator windings are in the same position. When the rotor of the transmitter turns, the rotor of the receiver will turn at similar angles.

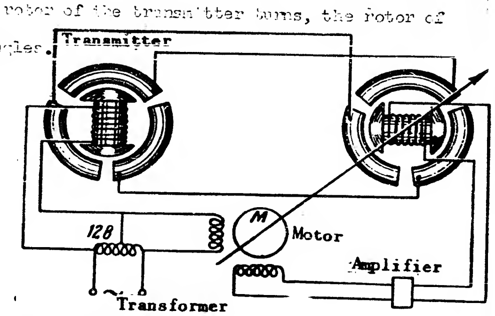

Fig. 216. Diagram of selsyn remote-control system.

Thus, any values can be transmitted in the form of angles at which the rotor of the transmitter and of the receiver turn.

With the help of selsyn remote-control systems which are more precise than potentiometric systems the ranging of the pieces is controlled.

Let us return now to the problem of forming the required angles of range by the guns.

109. The Formation of Angles Required to Hit the Target in Remote-Control Firing Installations

All the corrections computed above are, as we know, corrections to allow for the initial angles at which the guns are adjusted. They are determined by the

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by the angles of sighting at the target, i.e. the angle-off of the target ψ, and the angle of site ξ. In other words, at the initial moment, the piece is adjusted in parallel direction to the sight axis and then it is ranged more precisely by making allowance for total corrections in lead, lag, drop and parallax.

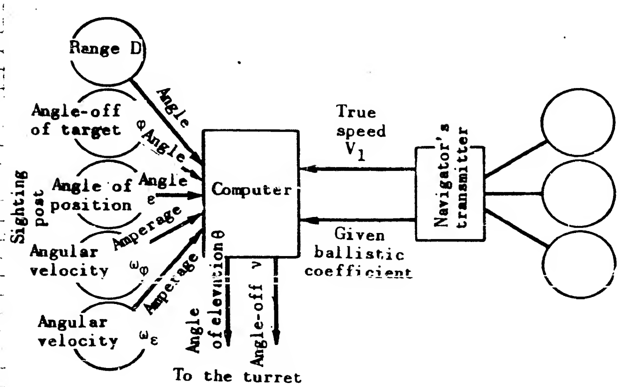

Fig.217 Simplified diagram of operation of the sight of a remote-control firing installation.

For the sake of convenience we shall refer to the entire complex of devices that calculate the corrections for the angles at which the piece is adjusted by one definition—we shall call it the computer.

When the computer does not work, the gun-barrel must be maintained in a position parallel to the sight axis while the target is being tracked. For that purpose, the viewer of the sight-mechanism is connected with the rotors of the selsyn transmitters through a system of reduction gears. One of the rotors registers the angles at which the viewer turns in the horizontal plane, the others — the vertical angles. The turn of the rotors of the selsyn transmitters makes special motors for the vertical and horizontal adjustment turn the piece by the same angle as the angle by which the viewer of the sight-mechanism has turned since the sight-mechanism and the piece are connected by the selsyn system, the work of which has been reported above.

Here is how the computer operates.

The range to the target D, the angle-off of the target ψ, the angle of site δ, and horizontal angular target velocity ω_γ and its vertical velocity ω_ε are signalled to the computer from the viewer. All these data are determined and transmitted to the computer regardless of the gunner's actions as long as he tracks the target with the beam of the viewer and frames the target by the diamond-shaped pips of the range finder.

Corrections in lead, lag and drop depend on the actual aerial velocity V_1 of the own aircraft and the ballistic coefficient c . These values are computed by a special decisive mechanism according to data signalled by aeronautic instruments and according to the value of ballistic coefficient c. They are eventually transmitted to the computer in the form of additional rheostat resistances.

According to the data obtained in the computer all necessary corrections are individually made. There are separate mechanisms to compute these corrections individually. Then, the corrections for the angle of position and the angle-off of the target are summed up for each angle individually by a special adding mechanism and then the computer indicates the necessary angles at which the piece must be adjusted by rotor movements of differential selsyns, located in the computer and switched in between the selsyn transmitters of the sight-mechanism and the selsyn-receivers of the turret. We should like to mention, that to begin with the computer receives angles of sighting φ and ε, while the corrections for drop, lag and parallax depend on the precise angles of pointing ν and θ, as we can see from the above-mentioned formulas. For that reason, the angles at which the piece turns are transmitted to the computer by the differential selsyns, so that more accurate values for these corrections can be obtained. Upon receiving this data, the computer works out new and more precise corrections. Adjusting of the piece will be more exact thereafter, its new angles will again be signalled to the computer, the latter will produce even more exact corrections, etc. until the values of these additional corrections will be reduced to zero and the piece set up precisely.

This process takes place continuously while the target is being tracked.

The power operation of controlling the piece is rather complicated and we shall refrain from dwelling on it.

Thus, the task of adjusting the guns according to the basic data is solved by an extremely complex system of devices and mechanisms which we have discussed in general terms. But even such rather superficial study makes it possible to judge all the theoretical and technical difficulties of this task. Despite the enormous complexity of the system of remote-control firing the gunner's operation is reduced to mechanical work -- tracking the target and framing it by the diamond-shaped pips of the range finder. The gunner's task does not differ from the pilot's task in firing with an automatic gun-sight. The only difference lies in the fact that sighting is done by the gunner in turning the viewer of the sight-mechanism by hand while the pilot has to maneuver the entire aircraft.

110. Brief Outline of the Significance of Remote-Control Firing Installations

The fact, that the gunner does not directly operate the guns leads to considerable complications in regard to the installation and the sight-mechanism. It entails the introduction of a series of mechanisms, electric devices, power parts and various remote-control gears and systems. The great number of devices of which each plays an important role in sighting or adjusting the guns requires special care so as to keep the whole system working.

But despite the complexity and the relative high cost of the remote-control firing installations, they are, undoubtedly, very promising and have exerted a great influence on the development of heavy airplane construction.

We cannot imagine a modern airplane that travels at high altitudes without pressurized cabins. This fact alone requires that the gunner be removed from the guns since the firing installations cannot possibly be set up in pressurized cabins.

After the task of operating remote-control installations was solved, a

the possibility arose of placing each gunner comfortably in a position from where he could see best. As a result, the accuracy of sighting is greatly increased since neither the gunner nor the sight-mechanism are affected by shocks, noise of motors or firing. The defense ability of aircrafts is greatly increased by uniting several installations into one system that can be operated by two or even three gunners at different locations.

Fire effectiveness is greatly increased by a thorough theoretical and technical study of the problem of adjustments in accordance with corrections and by the preciseness with which the computing devices work.

This will close our report on the practical aspects of aerial gunnery.

CONCLUSION

Modern science and technology develop rapidly and advance constantly.

The high speed and altitudes at which modern airplanes operate, affect the methods and techniques of aerial combat requiring constant introduction of more precise data into the theory of aerial gunnery, and calling for continuous improvements in sighting-mechanisms, guns and firing installations. The sighting-mechanisms discussed in this book are not fully up to-date. We have reported on them by way of illustrating how to solve problems of aerial gunnery in different cases.

However, it does not mean that the problems taken up in this book have become obsolete and that it would be superfluous to study them.

We believe that a study of aerial gunnery and of the basic operations of sighting presented in a popular form, will greatly simplify the task of following serious courses in aerial gunnery.

The author feels that he has achieved his goal, if this book helped some of the readers to understand the practical aspects of the complex phenomena that are a part of aerial gunnery.